FINAL REPORT

## PHORETIC MITES FROM SOUTHERN PINE BEETLES ATTRACTED TO NON-STICKY TRAPS BAITED WITH FRONTALURE

Prepared by:

*John C. Moser*       *Oct 27, 1982*
_____      _____
John C. Moser                   Date
Research Entomologist

Approved by:

*Peter L. Lorio*      *10/27/82*
_____      _____
Peter L. Lorio, Jr.         Date
Project Leader
RWU 2203

One of the paradoxes of fundamental research is that spinoff data often becomes as/or more important than the original objectives; this study was no exception. The primary purpose of the study was to determine which mites were phoretic on the southern pine beetle (SPB) and if their abundance varied by season.

But to accomplish this objective, we had to invent a nonsticky trap (Moser and Browne 1978) which would capture SPB over a time span of at least one month without the pheromone bouquet losing attractancy. This trap worked so well that it was subsequently modified for use in other parts of the country for capturing other species of bark beetles.

When the SPB data were compiled it became obvious that we possessed not only the mite data desired, but the first continuous record of SPB flight catches over a year. The latter data was modeled to predict SPB flying populations (Moser and Dell 1979). Subsequent data yielded a similar predictive model for the clerid predator of the SPB. This study also produced strong evidence that the clerid controls the SPB under endemic conditions.

Further data gathered on a daily basis documented the minimum ($42^{O}F$), maximum ($105^{O}F$), and optimum ($80^{O}F$) temperatures for which the SPB flies (W. A. Thompson, Report).

Finally, another report by W. A. Thompson tallied the mites phoretic on flying SPB and showed that the common species varied in abundance by

season. Some of the more interesting mite parasites were a chigger and several chigger-like mites that parasitized flying adult SPB. Two were described (Moser and Vercammen-Grandjean 1979) and another paper documents their habits (Moser 1979).

FS-SO-2203-1.31 has so far generated 5 publications, all of which are attached. Also attached are the two summaries of statistical data by W. A. Thompson, discussed in this report, from which two or more other publications are planned.

This study is closed.

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# PARASITENGONA MITES (ACARINA: PROSTIGMATA) ASSOCIATED WITH FLYING ADULTS OF THE SOUTHERN PINE BEETLE [1,2]

J. C. Moser[3]

-----ABSTRACT—All motile instars (larva, nymph, and adult) of three Parasitengona families, Erythraeidae, Trombidiidae, and Trombiculidae, were taken from pheromone traps designed to catch male southern pine beetles. All but one of 14 specimens were parasitic or attached to flying adult beetles. The larvae rode on all body areas and were active only during the warm months. One trap caught most of the mites. Although these mites occur infrequently during certain seasons, they may have a limited local impact. -----

## INTRODUCTION

Members of the cohort Parasitengona Oudemans 1909 (Vercammen-Grandjean 1973) are generally parasitic in the larval stage and predaceous in the active nymphal and adult stages. All stages of the families Erythraeidae, Trombidiidae, and Trombiculidae, are often found on bark, whether the trees are infested by bark beetles or not (Lindquist and Vercammen-Grandjean 1971, Loomis 1956, Moser and Roton 1971).

In a recent study of flying adults of the southern pine beetle (Moser and Browne 1978), only 14 of 9,637 beetles had Parasitengona mites[4]. Each affected beetle carried one mite. This paper reports the occurrence of these rarely encountered mites, which differ so markedly from those associated with beetles in the inner bark of trees.

## METHODS AND MATERIALS

Placement of traps and collection of specimens:

Bucket traps as described by Moser and Browne (1978) were placed along the "front" of an infestation from November 1, 1974, through October 30, 1975, and were moved forward as the front advanced. The trapped beetles, 98.7% of which were males, were collected twice weekly, and their numbers recorded. Maximum air temperatures were recorded from a shaded maximum-minimum thermometer inside the infestation at a height of 1 meter above ground.

Each collection had 50 southern pine beetles and associated phoretic mites. The species and numbers of mites, as well as their locations on the insect bodies, were tallied.

## RESULTS AND DISCUSSION

Of the approximately 20,000 mites collected during the year the traps were in the field, 14 were Parasitengona (Table 1). The three erythraeids included one larva, one nymph, and one adult male. In this study erythraeids were active only in spring, although one larva was captured in August (Moser 1976). The chelicerae of the larval *Leptus* sp. were inserted into the gular region of the beetle's head (Fig. 1), and another larva was found on the elytra of a southern pine beetle (Moser 1976). Several larvae were attached to other insect associates of the beetle (Moser and Roton 1971).

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1. *Dendroctonus frontalis* Zimmerman 1868 (Coleoptera: Scolytidae).
2. Investigation supported in part by the USDA Southern Pine Beetle Program.
3. Southern Forest Experiment Station, USDA Forest Service, Pineville, Louisiana 71360 USA.

One trap caught two post-larval erythraeids (an unusual capture) identified by A. E. Treat as *Balaustium* von Heyden, species undetermined (Fig. 2). Phoresy upon insects by adult or deutonymphal erythraeids has not been previously reported. In this study, the mites seemed merely to be riding the beetles, which suggests phoresy, but the relationship may have been predatory. Treat states that he has seen a *Leptus* deutonymph ride for an hour or more on a larval insect much larger than itself, gradually parasitizing and sucking it dry.

The genus *Balaustium* may be an exception to the rule that Parasitengona larvae are parasitic. Putman (1970) documented that the larva of *B. putmani* Smiley, as well as the nymph and adult, was a free-living predator of soft-bodied arthropods on trees. Grandjean (1946) recorded that *B. florale* Grandjean, unlike other known erythraeid larvae, was vegetarian, feeding on pollen grains of *Ranunculus acris*, *Bellis perennis*, and *Acer campestris*. Smiley (1966) reported adult females of *Balaustium dowelli* Smiley feeding on eggs of *Heliothis zea* (Boddie).

All known larval trombidiids parasitize only invertebrates. Larvae of two species, *Diathrombium diaphane* Moser and Vercammen-Grandjean 1978 and *Megophthrombium gracile* Moser and Vercammen-Grandjean 1978 were taken from beetles in traps. The two lost trombidiids (Table 1) may also have belonged to one of both of the two species. These trombidiids apparently become active at temperatures over 27°C, and will attach to any body region of the beetle. It may be significant that 7 of the 10 mites of these two species were retrieved from trap #8, one of 5-12 traps strung out in a line over the study area over the 12 months (Moser and Browne 1978). Apparently, trap #8 was close to a source where both species of trombidiids were present. Unlike the other traps located in the woods, trap #8 was adjacent to a ditch parallel to an asphalt road. Perhaps the trombidiids were part of this microenvironment. Climbing nearby beetle-infested trees, they attached to emerging beetles (Roton, 1978). Although there is some overlap in dates, the *D. diaphane* may seasonally occur as much as 2 months ahead of *M. gracile*.

The chigger, *Eutrombicula splendens* (Ewing 1913), a common pest of man, was retrieved from a beetle abdomen on August 8. Chiggers, or trombiculids, are so closely related to the trombidiids that the adults of the two families are indistinguishable (Krantz 1970). But parasitic behavior separates the two. Larval trombidiids always parasitize invertebrates, and with rare exceptions (Audy 1956, Suzuki 1976, Vercammen-Grandjean *et. al.* 1970), the trombiculids parasitize vertebrates.

According to Baker and others (1956), *E. splendens*, one of the most common causes of dermatitis (trombidiosis) of man in the southeastern United States, prefers moist habitats such as swamps, bogs, rotten logs, and stumps, and will parasitize any terrestrial vertebrate. Snakes and turtles are its most common hosts. In the southern United States, larval activity may last all year if ground temperatures remain warm.

The *E. splendens* larva was first identified by E. E. Lindquist, and identification was confirmed by R. B. Loomis and P. H. Vercammen-Grandjean. Although the larva appeared to be attached to the beetle when collected, R. B. Loomis found no evidence of engorgement or of any material around the chelae, and concluded that the larva may never have attached. Because larvae of *E. splendens* are abundant in dead standing and fallen pine trees in Louisiana and Mississippi, Loomis postulated that the larva was either "riding" on the beetle, or may have arrived in the trap by some other manner. There is, however, at least one other record of chiggers attached to a flying insect. Audy (1956) documented engorged larvae of the scrub typhus vector, *Trombicula deliensis* Walch 1922, that were found attached symmetrically to the metanotum of a small tipulid fly that flew onto the writer's worktable.

## CONCLUSIONS

Unlike most other species of mites associated with flying adults of the southern pine beetle, the Parasitengona range the outer bark and presumably attach to beetles during, or shortly after, emergence (Roton, 1978).

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A. E. Treat, 51 Colonial Parkway, Dumont, New Jersey 07628, personal communication.

TABLE 1.  Parasitengona mites caught in pheromone-baited bucket traps with flying southern pine beetles.

| Family and Scientific Name | Stage[1] | 1975 Date Trapped | C°Maximum Temperature | Trap | Beetle body part attached to |
|---|---|---|---|---|---|
| **ERYTHRAEIDAE** | | | | | |
| *Leptus* sp. | L | III/27 | 23.5 | 4 | head |
| *Balaustium* sp. | N | IV/17 | 25 | 5 | thorax, ventral |
| " | M | IV/28 | 29.5 | 5 | thorax, ventral |
| **TROMBIDIIDAE** | | | | | |
| *Diathrombium diaphane* M&V-G. 1979 | L | V/8 | 28 | 8 | head |
| " | L | V/19 | 29 | 8 | abdomen, ventral |
| " | L | V/26 | 31 | 8 | head |
| " | L | " | 31 | 8 | thorax, dorsal |
| " | L | VII/7 | 33.5 | 13 | " |
| *Megophthrombium gracile* M&V-G. 1979 | L | VII/3 | 30 | 8 | head |
| " | L | VII/17 | 31 | 8 | "in water2" |
| " M&V-G. 1979 | L | X/9 | 27 | 17 | abdomen, ventral |
| Trombidiidae sp.[3] | L | VI/2 | 28 | 8 | head |
| " "[3] | L | VI/5 | 30.5 | 4 | abdomen, ventral |
| **TROMBICULIDAE** | | | | | |
| *Eutrombicula splendens* (Ewing 1913) | L | VIII/11 | 30.5 | 10 | abdomen, ventral |

1/L= larva, N= nymph, M= male.

2/Mite found floating in water in bucket trap, not attached to beetle.

3/Identified as trombidiids, but lost before they could be mounted on slides and identified more precisely.

# A NONDESTRUCTIVE TRAP FOR *Dendroctonus frontalis* ZIMMERMAN (COLEOPTERA: SCOLYTIDAE)

## JOHN C. MOSER[1] AND LLOYD E. BROWNE[2]

[1] *Southern Forest Experiment Station, Forest Service—USDA*
*Pineville, Lousiana 71360*
[2] *Division of Entomology, University of California*
*Berkeley, California 94720*

**Abstract**—The bucket trap is a lightweight device for capturing southern pine beetles in flight and retaining them either alive or dead for later examination. It is not messy like the sticky trap and not cumbersome like conventional live traps. Placing the bucket against a vertical silhouette increases the number of beetles caught. Few nontarget insects are captured except for the clerid *Thanasimus dubius.* When the trap was baited with Frontalure, about 99% of the beetles trapped were male. When infested pine bolts were used as bait, roughly equal numbers of males and females were captured.

**Key Words**—southern pine beetle, *Dendroctonus frontalis,* bucket trap, Frontalure, *Thanasimus dubius.*

## INTRODUCTION

Southern pine beetles (*Dendroctonus frontalis* Zimmerman) in flight are normally captured with live traps, such as rotating nets and sleeve funnels, or with sticky traps (Gara, 1967; Gara et al. 1965). Live traps, however, are large, bulky, and require power sources. Sticky traps, though lightweight, portable, and suitable for synthetic pheromone baits, catch many nontarget organisms as well as debris; moreover, beetles become so mired in the sticky material that they are of little use for chemical investigations and other studies (Moser, 1976).

This paper describes an improved bucket trap that is as lightweight, portable, and easy to bait as the sticky trap but catches few if any nontarget insects. It can retain trapped beetles either alive or dead, and it has none of the messy features of sticky traps.
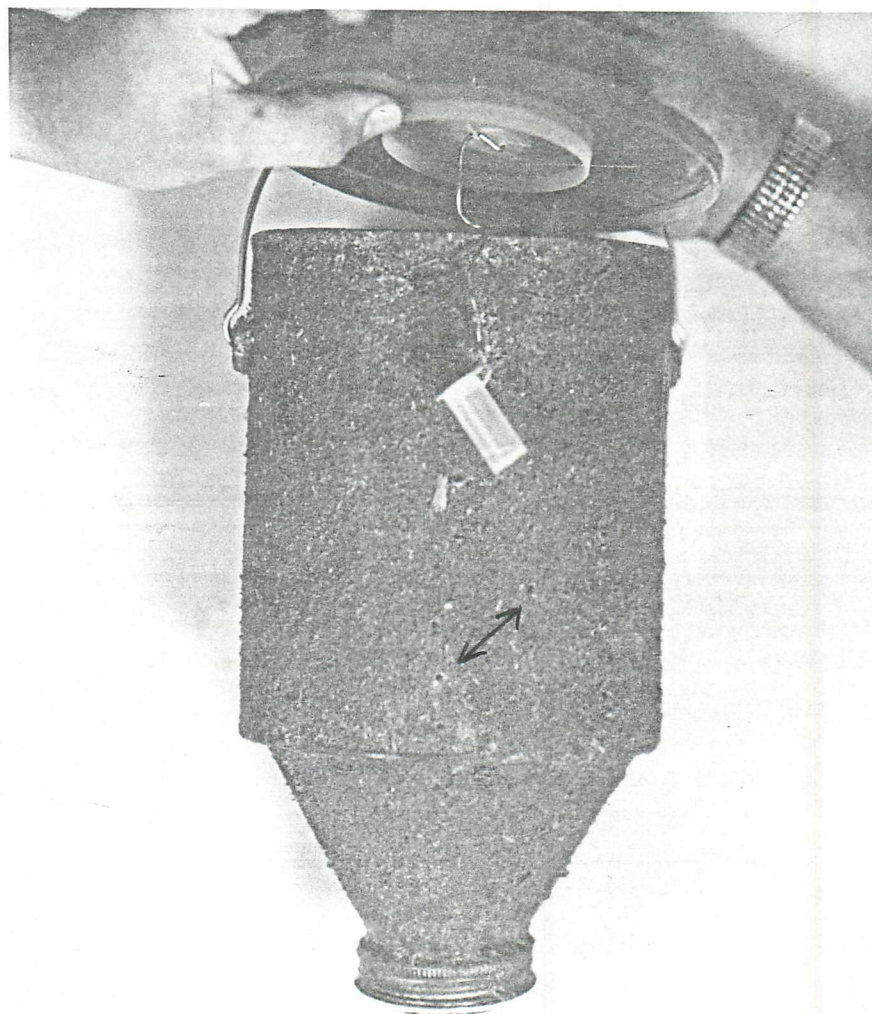
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FIG. 1.   The bucket trap with Frontalure-containing vial exposed. Beetles enter
through the holes (arrow) and drop into jar which contains water.

## METHODS AND MATERIALS

### Trap Construction

The trap consists of a 1-gal (3.79-liter) paint bucket with top and bottom removed (Fig. 1). A 16-cm (top diameter) metal funnel was soldered to the lower end; a mason jar rim was soldered to the narrow end of the funnel, and a 0.5 pt (0.24-liter) glass jar was connected to the rim. The top of the can was covered by a plastic lid; a 2.5-ml polyethylene snap-cap vial containing 20 drops (0.3 ml) of the attractant Frontalure,[3] a mixture of 1 part frontalin to 2 parts α-pinene (Vité, 1970) was suspended by a stiff wire from the center of the lid. Seventy-two entry holes (2-mm diam) were punched in the can in eight equidistant vertical rows. To minimize rain entering the holes, the upper rim of each was bent out with a punch to form hoodlike shields. One advantage of the trap is that it provides for a walking response in addition to the flying response. To provide a walking surface for the beetles, the can was first painted with water-soluble white glue and then rolled in sawdust; after drying, the can was sprayed with a light coat of red enamel, a color that appears to be highly attractive to flying adults (Nash, 1970). Insects entering the holes fell down the funnel into the glass jar. To collect living specimens, it was necessary to place tissue paper in the jar because the beetles would otherwise concentrate at the bottom and chew off each other's legs and antennae. If dead beetles were desired, water was placed in the jar instead of paper.

### Field Placement of Traps

To test the bucket traps, an infestation was artificially started in fall 1973 by baiting several trees with Frontalure in a *Pinus taeda* L. stand in Rapides Parish, Louisiana. The spot was maintained and directed by continuous baiting of new trees just ahead of the line of newly infested trees, which generally advances in only one direction away from the initial attractant source (Gara and Coster, 1968). This line is commonly referred to as a "front" because of its analogy to weather systems. After 10 mo., the spot encompassed about 1 ha and consisted of approximately 250 trees, about one-third of which contained live beetles. Traps were set out November 4, 1974, and tested through November 1, 1975, being inspected twice weekly. Our traps were about 20 m ahead of the front among uninfested trees along a line facing the spot's south end. Traps were placed about 9 m apart and were moved forward as the front advanced. The number of traps varied from 5 to 12 because only those with sustained large catches were retained.

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[3] Mention of trade names is solely to identify materials used and does not imply endorsement by the U.S. Department of Agriculture.

FIG. 2.   Field placement of bucket trap.

Traps were initially hung with strings from tree branches, but very few beetles were captured until a vertical silhouette was added. Subsequently, buckets were suspended about 4 m high from pulleys against $1 \times 30 \times 400$-cm plywood boards (Fig. 2). These "artificial trees" had the added advantage of being highly mobile.

When a high percentage of the captured beetles turned out to be males, it was necessary to determine if trap design or bait was responsible. Therefore, two bolts of *Pinus taeda* naturally infested with both sexes of southern pine beetles were screened and placed inside each of two bucket traps. In addition, three bucket traps baited with Frontalure and coated with Stickem Special® were set out.

Because large numbers of flying adults have been caught on sticky traps in or near infestations (Reeve, 1975), three pairs of bucket traps were tested to see whether the beetles would enter unbaited bucket traps. Each pair consisted of one trap baited with Frontalure and a twin without Frontalure in the plastic vial. The three pairs were placed in a line along the front of a spot from 6 to 15 m ahead of the infested trees. Individual traps within pairs were separated by about 5 m, and pairs were separated by about 10 m. A total of eight collections were made twice weekly from April 26 through May 20, 1977. After the beetles from each pair of traps were collected, a coin was flipped. If the toss was "heads," positions of the baited and unbaited buckets were switched so that the relative positions of buckets within pairs remained at random.

## RESULTS AND DISCUSSION

During a trapping period of 12 mo., a total of 9637 southern pine beetles were caught. Collections improved after the buckets were suspended against plywood boards, apparently because many scolytids (including *D. frontalis*) orient in flight to vertical objects (Henson, 1962; Gara et al., 1965; Rudinsky, 1966; Shepard, 1966; Billings et al., 1976). Traps consistently collecting the most beetles were located in open areas, which provided the beetle with aerial pathways, whereas traps in obstructed areas were inefficient.

Of 1512 beetles examined for sex determination, the majority (98.7%) were males, as determined by clearing the beetles in lactophenol and examining the genitalia. Our data support Hughes' (1976) observation that fewer females than males are attracted to point sources of frontalin. Perhaps the bucket trap simulates a newly initiated female gallery, which, like the trap, attracts only males.

Tests with infested bolts indicated that the bait and not the trap's design was responsible for the high percentage of males captured. One of the buckets containing infested bolts trapped 14 males and 13 females; the other trapped 12 males and 8 females. The traps baited with Frontalure and coated with Stickem Special® captured 242 males, of which 104 were found inside the collecting jar and 138 were stuck to the outside of the can. No females were collected.

Tests with baited vs. unbaited traps likewise showed that the trap's design did not attract beetles. A total of 155 males and 2 females were trapped in the baited buckets during the 4-wk period; no beetles were found in the unbaited buckets. Totals for each collecting date varied from 2 to 41 beetles.

This trap design may be of limited usefulness for attracting other bark beetle species. Small-scale tests with *Dendroctonus brevicomis* (Lec.) in Madera County, California, and with *Scolytus multistriatus* (Marsham) at Delaware, Ohio, showed that bucket traps baited with pheromones that attracted hundreds of beetles to nearby conventional traps caught only one or two beetles each.

In addition to the southern pine beetle, specimens of the following insect species were captured: *Corticeus glaber* LeConte, *Ganascus ventricosus* (LeConte), *Hylastes porculus* Erichson, *Ips avulsus* (Eichhoff), *I. calligraphus* (Germar), *I. grandicollis* (Eichhoff), *Lyctocoris elongatus* (Reuter), *Osmita colon* (L.), *Platydema flavipes* (F.), and *Thanasimus dubius* (F.). Only one or two specimens of each were found, with the exception of *T. dubius*, of which 258 were collected. This species as well as other clerids are known for their attraction to bark beetle pheromones (Wood et al., 1968; Vité and Williamson, 1970; Rudinsky et al., 1971; Whittaker and Feeny, 1971; Pitman, 1973). All except *G. ventricosus*, *H. porculus*, and *O. colon* were previously listed as southern pine beetle associates (Overgaard, 1968; Moser et al., 1971). The euglenid *G. ventricosus* is associated with scolytid-infested trees, where they oviposit in decaying wood (F. G. Werner, University of Arizona, personal correspondence). Adults of the scolytid *H. porculus* are attracted to freshly cut lumber, and breed in stumps and roots of dying pines (Baker, 1972). Furniss and Schmitz (1971) found four related species of *Hylastes* attracted to frontalin and other tree volatiles. W. A. Connel, of the University of Delaware (personal communication), regards the capture of nitidulid *O. colon* as accidental, although this pest of stored products is often attracted to volatiles emanating from decomposing vegetation or fermentation.

*Addenda to Proof.* Dr. G.D. Amman reports that in August, 1977, at Ogden, Utah, bucket traps baited with linalool, the *Ips pini* (Say) attractant, failed to attract any beetles. Bucket traps containing screened bolts naturally infested with *Ips pini* attracted flying adults of both *Ips pini* and *Pithophthorus* sp.

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# MEGOPHTHROMBIUM GRACILE N.SP. AND DIATHROMBIUM DIAPHANE N.G., N.SP. (ACARINA: TROMBIDIIDAE), TWO LARVAL PARASITES OF ADULT SOUTHERN PINE BEETLES [1,2]

J. C. Moser[3] and P. H. Vercammen-Grandjean[4]

----- ABSTRACT— One new genus and two new species are described and illustrated.  Larvae of both were recovered as parasites of flying adults of *Dendroctonus frontalis*.  -----

Described herein are a new genus and two species of Trombidiidae.  Their biology as parasites of the southern pine beetle is discussed elsewhere (Moser, 1979).

One species belongs to *Megophthrombium*[5], a genus recently erected by Mullen and Vercammen-Grandjean (1978), which presently includes the larvae of two species parasitic on mosquito adults from New York and Illinois.  Existing keys place the other species near the genera *Microtrombidium* and *Ettmuelleria*, but it clearly belongs to neither.  The systematic positions of both *Megophthrombium* and our new genus are vague because most of the other genera of the Microtrombidiinae were based on adult characters; little is known of their larval stages (Vercammen-Grandjean 1973).

For the following descriptions, we suggest the neologisms "stephanostome" and "stolascutum".

*Stephanostome:* (Plates A and B, Figure 5): (= buccal crown); replaces the term "buccal acetabulum"; this structure is often supported by an intero-basal sclerous and festooned armature (truss-frame).

*Stolascutum:* scutum with anterolateral flaps recurving ventrally; occurs in the Microtrombidiinae.

Three other terms used, *"lophotrix"*, *"scopa"*, and *"smilum"*, are usually seen only in the trombiculid literature.  They were recently difined by Mullen and Vercammen-Grandjean (1978).  *Odontus*, a term suggested by Newell (1957) is more appropriate and shorter than "palpotibial claw", which is no "claw".

Genus *Megophthrombium* Mullen and V-G 1978

TYPE SPECIES—*Megophthrombium welleslyi* Mullen and V-G, 1978.

DIAGNOSIS— MICROTROMBIDIINAE of medium to large size (Ip= 710-970).  SIF= 7N. T-N-2-2110.0000.  F $P_p$= 0/0/nnN. *Body*: elongate & pyriform, poorly sclerotized; provided with huge eyes  especially the anterior pair of corneas ($\emptyset$ 22-44 $\mu$); body setae rather long, thin and barbed, fD= 244662 (2)= 26 [ (2) stands for pygosomalae], fV= 22$\mu$= 4 [u stands for uropore], NDV= 30, inserted on conical disks or plates, 4 larger anterior plates. *Scutum: stolascutum* type, not pleated fine porosity, with 3 x 2 peripheral setae and 2 scarcely ciliated trichobothria (Tb) or

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1. *Dendroctonus frontalis* Zimmerman 1868 (Coleoptera: Scolytidae).
2. Investigation supported in part by the USDA Southern Pine Beetle Program.
3. Southern Forest Experiment Station, U. S. Forest Service, Pineville, Louisiana 71360.
4. 2062 20th Avenue, San Francisco, California 94116.
5. *Megophthrombium:* contraction for the Greek terms, "mega" (large), "opthalmos" (eye), and *Thrombium*.

# *Megophthrombium gracile*
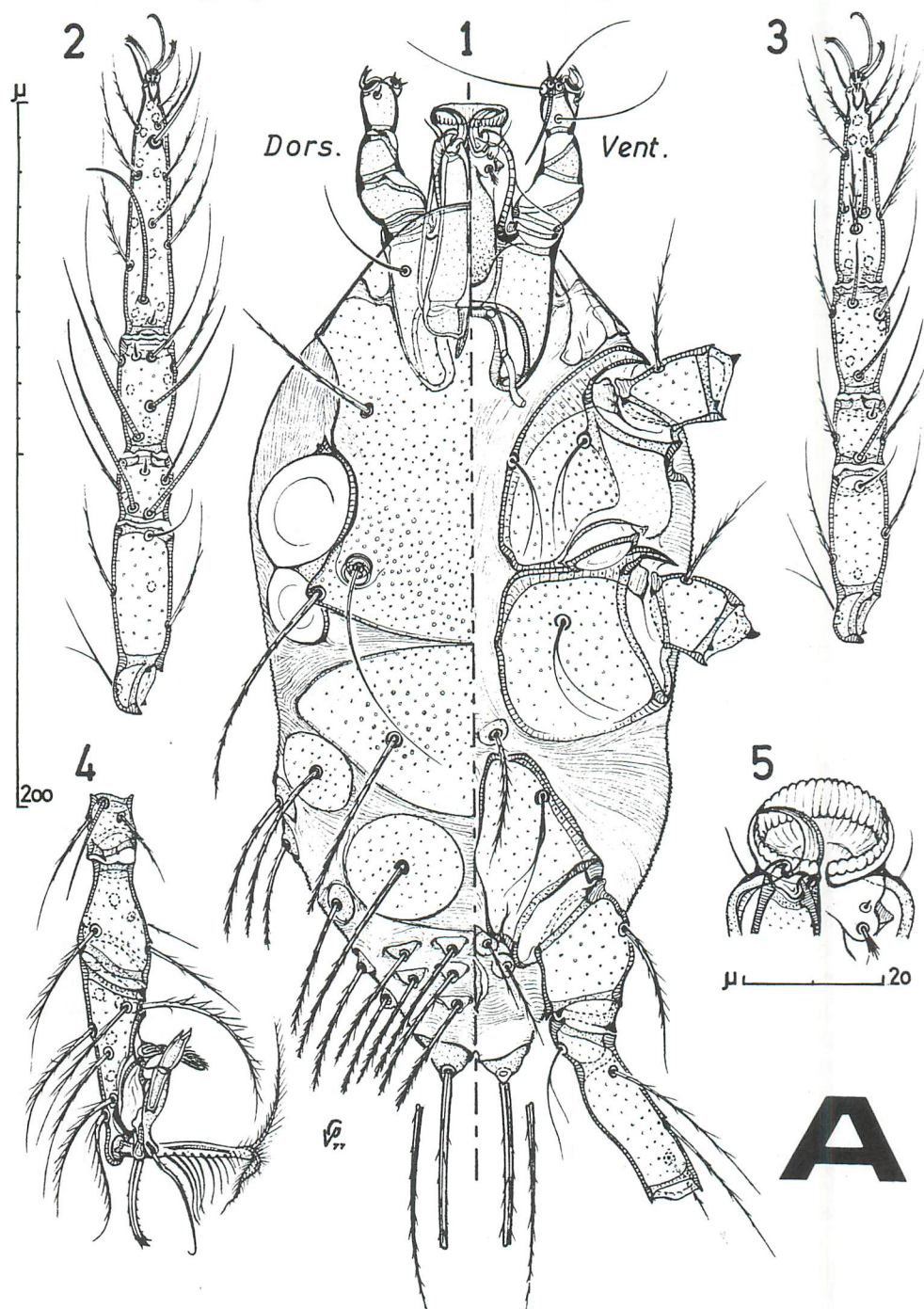


Figs. 1-5: *Megophthrombium gracile* n. sp. - 1, body (dorsum left, venter right); 2, front leg (dorsal); 3, middle leg (dorsal); 4, hind leg (half profile); 5, stephanostome.

# Diathrombium diaphane
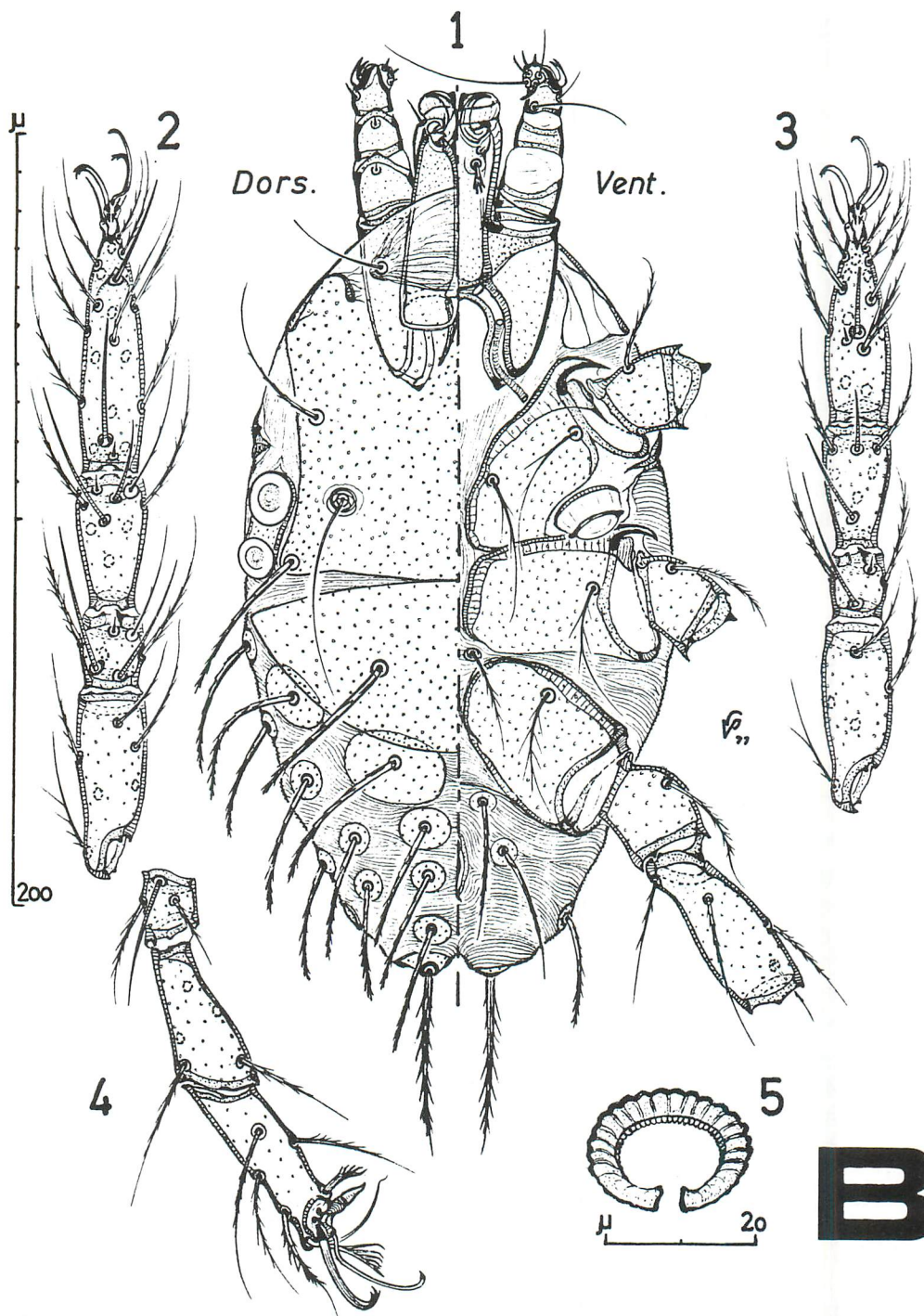


Figs. 1-5:*Diathrombium diaphane* n. g. , n. sp. - 1, body (dorsum left, venter right); 2, front leg (dorsal); 3, middle leg (dorsal); 4, hind leg (half profile); 5, stephanostome.

bottom (17μ). *Galea*: (32μ), protorostrala (7μ), deutorostrala (2μ), tritorostrala (8μ), chiroid (4 thin digits). *Supracoxalae* (?), indistinguishable. *Front leg* (Plate B, Fig. 2): longest tarsus (66μ), bearing a long pointed $S_1$ (33μ); $f_1$ (4μ), ST (29μ), PT' (14μ), terminally 2 claws (trifurcate apex) and empodium simple; tibia (34μ) with 2 tibialae (21 and 39μ) and an apicodorsal micro-tibiala (4μ); genu (19μ), with 2 genualae (34 and 40μ) and an apicodorsal microgenuala (4μ); femur (38μ); trochanter (37μ); coxa (52μ) with 2 branched setae. *Middle leg* (Plate B, Fig. 3): tarsus (52μ), bearing a $S_2$ (18μ) with its $f_2$ (3.5μ) and nearby *stachus* (25μ), PT'' (14μ), and terminally 2 claws (trifurcate apex), plus a simple empodium; tibia (31μ), with 2 tibialae (16 and 27μ); genu (17μ), with one genuala (41μ) and an apicodorsal microgenuala (4μ); femur (37μ); trochanter (35μ); coxa (44μ), with one branched seta. *Hind leg* (Figs. 1,4): tarsus (52μ), bearing a subterminal *scopa* (10μ), and terminally 1 normal outer claw (24μ) and empodium (26μ), 1 *smilum* (8μ), and 1 *lophotrix* (22μ, 5 branches); tibia (34μ); genu (18μ), with one genuala (34μ); femur (40μ); trochanter (38μ); coxa (46μ) with a single branched seta. *Urstigma* prominent, between antero-and mid-coxa (Ø 12μ).

TYPE DATA—Holotype larva, on head of adult southern pine beetle, *Dendroctonus frontalis*; Rapides Parish, Louisiana, U.S.A.; 8 May 1975; collected by J.C. Moser.

## LITERATURE CITED

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Mullen, G.R., and P.H. Vercammen-Grandjean. (1978). *Megophthrombium*, a new genus in the family Trombidiiae (Acari: Parasitengona) from North American mosquitoes. Int. J. Acarol. 4: 39-45.

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Vercammen-Grandjean, P.H. (1973). Sur les status de la famille des Trombidiidae Leach, 1815 (Acarina, Prostigmata). [On the rules for the family Trombidiidae Leach] Acarologia 15: 102-114.

Statistical Summary

MITES OF SPB - Study 1.31; September 1974 - October 1975

W. A. Thompson

September 24, 1982

The objective of this analysis was to identify patterns of associa-
tion between numbers of mites of different species and then to determine
whether different patterns were associated with different environmental
conditions, including location and season of sample.  As an extreme
example of differences in pattern, suppose that several samples of southern
pine beetles carries only species #1, averaging 50 mites per beetle, and
that a second group of samples carried both species #2 and #3, averaging
20 and 40 mites per beetle, respectively.  We would then seek correlations
between these two distinct patterns of mites and environmental variables,
such as temperature, time of year, and sample site.

Data were collected from 122 samples of SPB over a 14-month period
from three different SPB infestations.  Samples were collected twice a
week, and maximum and minimum temperatures recorded.  From each sample of
beetles, fifty were checked for mites (or on the rare occasions when less
than fifty beetles were trapped, all beetles were checked and their numbers
recorded).  Twenty-five species of mites were recorded (Table 1), of
which only eight species--#1-4, #6-8, and #14--were sufficiently common
to be suitable for statistical analysis.

The analysis of these data proved more complicated than that from the
1.24 study for several reasons:  beetle flight is suppressed at low tempera-
tures, giving small samples at times; a single sample included beetles

(and hence mites) from more than one tree; and beetles from a single tree emerged over a many day period, thus showing up in many different samples, rather than all being in one sample (as in study 1.24).  Taken together, these factors caused a greater variance within samples (i.e. between beetles captured in a single sample), making it difficult to identify sharp patterns.

Two results were evident in relation to overall abundance of southern pine beetles and mites.  Samples of beetles taken during 3½ day periods with maximum temperature of 60°F or below had very few beetles (5 or less).  Fortunately, there were few such samples (only 10), and they were spread over several months.  Second, there was a significant difference in the percentage of beetles carrying mites during winter (January-March) than in other months.  During winter an average of 44% of the SPB carried one or more mites (range 0-76%), while the average was 72% for all other seasons (range 40-100%).  This difference is highly significant (t=6.83, p<.0001) and results entirely from the lower abundance of mites in winter, not from smaller samples of SPB in winter.  Average winter sample size of SPB was 41, while the average was 45 SPB for all other seasons (t=1.09, not significant).

An analysis of variance by month showed that many of the mite species varied significantly in abundance from month to month:  Species #1 - *Tarsonemus krantzi*; #3 - *Trichouropoda australis*; #4 - *Tarsonemus ips*; and #7 - *Histiostoma varia* (p<.0001 in all cases).  These results arise largely from the greatly reduced number of mites and mites per SPB during the four coldest months (December-March).  However, temporal abundances vary from species to species (Figure 1).  Species #1 (*Tarsonemus krantzi*) is found commonly

throughout the year.  It is generally the most abundant species, averaging three mites per beetle in January, and higher in other months.  Species #2 (*Dendrolaelaps neodisetus*) is common in summer, dropping to one to two mites per SPB in fall and winter.  Species #3 (*Trichouropoda australis*) is similar in abundance to species #2, but with a larger and statistically significant difference in mite numbers from fall/winter to spring/summer. Species #4 (*Tarsonemus ips*) disappears entirely in November, and does not reappear until June.  It is common (2 per SPB) only in August and September. Species #6 (*Ereynetoides scutulis*) is never common.  It disappeared in December and January, and peaked in abundance (average of 0.5 per SPB) in September and October.  Species #7 (*Histiostoma varia*) was mostly absent from November through May (only 1 found) with numbers increasing from June through September (1 or more per SPB).  Species #8 (*Macrocheles boudreauxi* showed no particular pattern of abundance, being absent-rare in winter (December-March) and only slightly more abundant at other times. Species #14 (*Pygmephorellus bennetti*) showed a sharp pattern of rarity for November and December (average of 0.3 per SPB), total absence from January through May, and high abundance from June through October (1-3 per SPB).

A cluster analysis was performed on the data using mites per beetle for each of the eight commoner species as the independent variables. Five clusters were identified, with only three species critical in defining the clusters:  species #1 - *Tarsonemus krantzi*; #4 - *Tarsonemus ips*; and #14 - *Pygmephorellus bennetti*.  Table 2 gives the clusters as defined by these three species, and figure depicts the division into clusters in the form of a key.

Unlike study 1.24, the clusters did not correlate so neatly with either site or season of samples.  Clusters 2, 4, and 5 were found only in summer and early fall, whereas clusters 1 and 3 were found throughout the year.  This distinction corresponds to the high abundance of *Tarsonemus ips* and *Pygmephorellus bennetti* during summer and early fall, and their low abundance at other times.

Table 1:  Mites of SPB - Study 1.31

| Mite ID number | | Code letters | Mite species |
|---|---|---|---|
| 1. | | Tk | Tarsonemus krantzi |
| 2. | | Dn | Dendrolaelaps neodisetus |
| 3. | | Ta | Trichouropoda australis |
| 4. | | Ti | Tarsonemus ips |
| 5. | | Ha | Histiogaster arborsignis |
| 6. | | Ea | Ereynetoides scutulis |
| 7. | | Hv | Histiostoma varia |
| 8. | | Mb | Macrocheles boudreauxi |
| 9. | 1/ | Pd | Proctolaelaps dendroctoni |
| 10. | | Hl | Heterotarsonemus lindquisti |
| 11. | | Lc | Longoseius cuniculus |
| 12. | | Pl | Proctogastrolaelaps libris |
| 13. | 1/ | Hs | Histiostoma sordida |
| 14. | | ♂b | Pygmephorellus bennetti |
| 15. | | Tp | Tyrophagus putrescentiae |
| 16. | | Th | Trichouropoda hirsuta |
| 17. | | Zsp | Zygoribatula, sp. |
| 18. | | Lsp | Leptus, sp. |
| 19. | | Esp | Erythraeidae, sp. |
| 20. | 1/ | Dv | Dendrolaelaps varipunctatus |
| 21. | | Tsp | Trombidiidae, sp. |
| 22. | | Osp | Oribatei, sp. |
| 23. | | Hsp | Hemileius, sp. |
| 24. | | Msp | Metaleius, sp. |
| 25. | | Psp | Paraleius, sp. |
| 26. | | Dd | Diathrombium diaphane |
| 27. | | Mg | Megophthrombium gracile |
| 28. | | En | Eutrombicula splendens |

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1/ Species #9, 13, and 20 were never found on SPB, although they were found on other insects in the same traps.

| Species | Cluster | | | | |
| --- | --- | --- | --- | --- | --- |
| | 1 | 2 | 3 | 4 | 5 |
| #1 - Tarsonemus krantzi | 3.7 | 4.4 | 7.5 | 8.2 | 5.2 |
| #4 - Tarsonemus ips | 0.0 | 5.6 | 0.4 | 5.3 | 1.4 |
| #14 - Pygmephorellus bennetti | 0.3 | 2.3 | 0.5 | 1.4 | 12.6 |

Table 2:  Cluster centers for five clusters defined by abundance of mites per

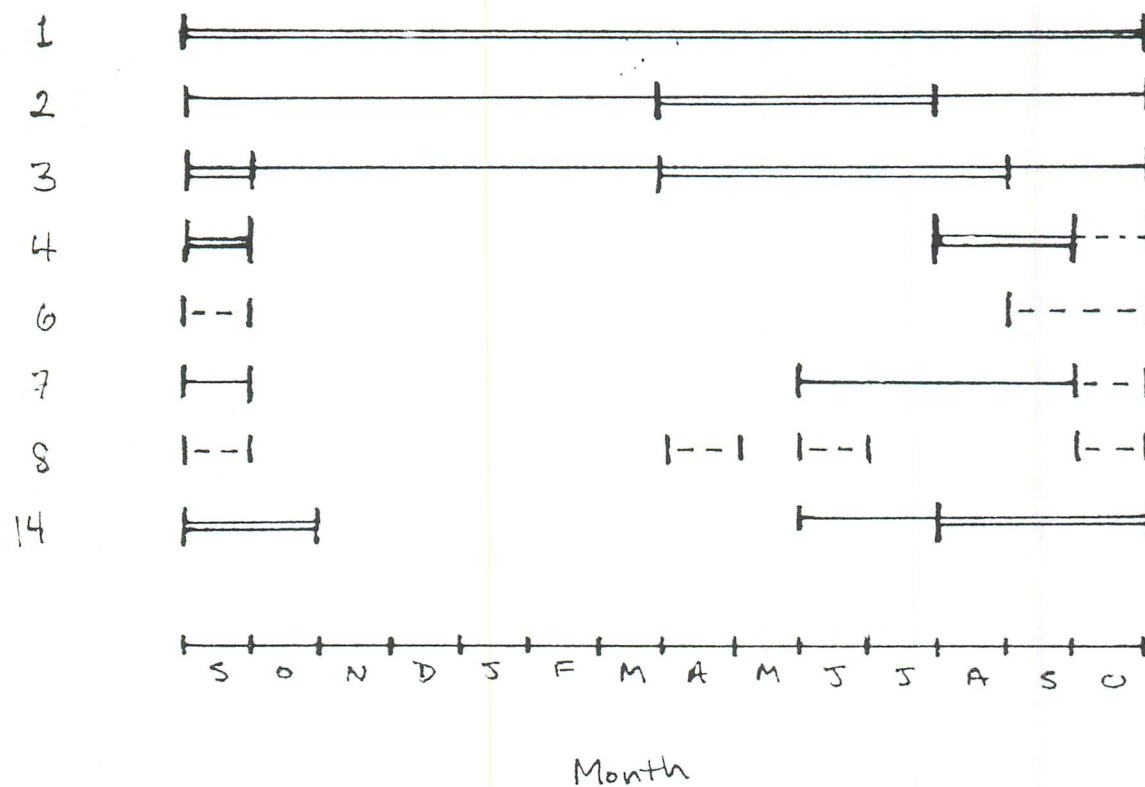SPB for the three key mite species.
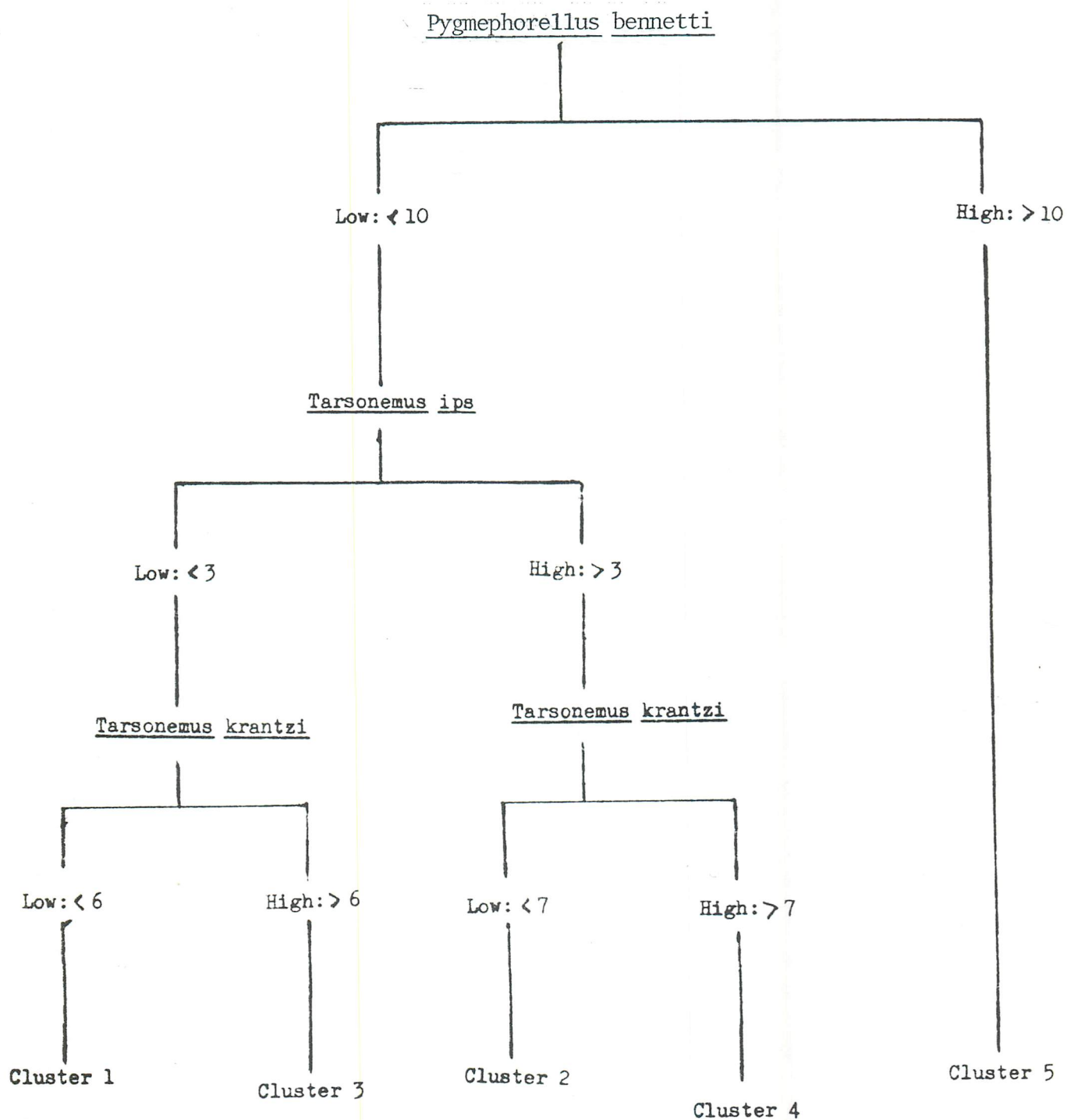
Species



Figure 1: Abundances of mites per SPB.

$\underline{\underline{\qquad}}$ = 2 or more

$\underline{\qquad}$ = 1-2

- - - = .5-1

Pygmephorellus bennetti

Low: < 10                                          High: > 10

Tarsonemus ips

Low: < 3                          High: > 3

Tarsonemus krantzi              Tarsonemus krantzi

Low: < 6        High: > 6        Low: < 7        High: > 7

Cluster 1                                                        Cluster 5
              Cluster 3        Cluster 2
                                              Cluster 4

**Figure** 2: Key for defining clusters in terms of the three key species of mites.

Statistical Summary

TEMPERATURE THRESHOLDS REGULATING FLIGHT OF THE SOUTHERN PINE BEETLE

W. A. Thompson

August 16, 1982

## 1. Introduction

In this paper we examine the flight activity of southern pine beetles (SPB) as a function of maximum daily temperature. Our primary concern is to test the following three hypotheses regarding flight activity at extreme temperatures:

H1 -- SPB do not fly at temperatures below $58^{o}F$;

H2 -- SPB propensity to fly drops precipitously as temperature declines toward some minimum temperature threshold;

H3 -- SPB propensity to fly drops off precipitously as temperature increases toward some maximum temperature threshold.

In addition, we will comment on other relationships of interest as revealed by the data, particularly differences in flight activity between SPB from an active infestation and from elsewhere.

## 2. Materials and Methods

### DATA

Data were gathered daily at two sites: Bentley, La. from September 1979 through December 1980; and Camp Livingston, La. from February 1979 through December 1980. For each site daily records were made of number of SPB caught in traps, maximum temperature, minimum temperature, and amount of rainfall. Numbers of SPB/trap/day are given for the two sample sites in figures 1 and 2. The Bentley data were collected from an active SPB infestation, until its collapse in June 1980. These data will be referred

to as the "outbreak" data set or B1 (9/79-6/80). Thereafter, there were
no active trees at the Bentley site (see figure 2). This later period will
be referred to as the "postoutbreak" data set, or B2 (7/80-12/80). There
were never any actively infested trees at the Livingston site during the
sample period. These data will be referred to as the "endemic" data set
(2/79-12/80). In addition, to allow pairwise comparisons with the Bentley
data, two subsets of the Camp Livingston data will occasionally be treated,
matching day for day the Bentley data: L1 (9/79-6/80) matching B1, and L2
(7/80-12/80) matching B2. Whenever there were no statistical counter-
indications, the data were combined to form the "pooled" data set. Table 1
summarizes these divisions.

## ANALYTIC MODELS

Two dependent variables were considered:

$S(T)$ = average number of SPB/trap/day for all sample days
with maximum temperature T;

$P(T)$ = percentage of days with maximum temperature T on
which SPB were caught.

For example, suppose that four days have maximum temperatures of $44^{O}F$.
On three of these days no beetles were caught, and on the fourth day one
beetle was caught. Finally, suppose that six traps were in use each of
the four days. Then, $S(44)$ = 1 SPB/6 traps/4 days = .04 SPB/trap/day.
and $P(44)$ = 100 x 1 day/4 days = 25%.

Only one independent variable was considered, T = maximum daily temperature ($^O$F). For the entire study T ranged from 32-101$^O$F. Since the minimum temperature at which a beetle was caught was 44$^O$F, we assumed in the regression analysis that P and S would both be zero for T<40$^O$F.

Four different models which we fitted to the data are reported here

$I_p$.   $P(T) = 0$                   for     T<40

         $= a_p + b_p T$         for $40 \leq T < X_p$

         $= c_p + d_p T$         for $X_p \leq T$

$I_S$.   $S(T) = 0$                   for     T<40

         $= a_S + b_S T$         for $40 \leq T < X_S$

         $+ c_S + d_S T$         for $X_S \leq T$

II.   $S(T) = 0$                 for     T<40

         $= \exp(f + gT)$      for $40 \leq T < Y$

         $+ \exp(h + jT)$      for $Y \leq T$

III.   $S(T) = 0$               for     T<40

         $= \exp(k + mT = nT^2)$    for $40 \leq T$

Models $I_p$ and $I_S$ are linear in T, each model having one line for the phase of increasing flight activity and another line for the decreasing phase. The temperature for these switches ($X_p$ and $X_S$) were estimated by trying a range of values around the peak of flight activity and selecting the ones which gave best least squares fits for the regression lines. Model II is exponential in T. Like the first models it has an increasing and a decreasing phase fit separately, with the switching temperature (Y) estimated as before. Model III is a Gaussian curve, i.e. exponential in T and $T^2$. Since this model automatically incorporates an increasing phase followed by a decreasing phase (for m>0 and n<0), no switching temperature needed to be estimated.

## 3. Results

### CAPTURE FREQUENCY - POOLED DATA

The lowest temperature at which a capture was recorded was $44^O$F. For the range $44$-$53^O$F, beetles were captured on 10 of 75 occasions (13%). For the range $54$-$60^O$F, beetles were captured nearly twice as often, 21 of 94 occasions (22%) (see Table 2).

Figure 3 shows the percentage of days on which SPB were caught for each temperature from 40 to $101^O$F, and the two regression lines fitted to this data. Southern pine beetle flight activity increased from 0% at about $42^O$F to 80-100% for $75$-$88^O$F, and then declined again to 0% at about $105^O$F.

$$\text{Model Ip.} \quad P(T) = 0 \qquad\qquad \text{for} \quad T < 40$$
$$= -80.0 + 1.91T \quad \text{for} \quad 40 \leq T < 89 \quad (R^2 = .791; \; p < .0001)$$
$$= 385 - \quad 3.66T \quad \text{for} \quad 89 \leq T \qquad (R^2 = .353; \; p < .05)$$

These equations imply that the minimum flight temperature is $42^O$F and the maximum flight temperature is $105^O$F.

These results led us to reject hypothesis one and to doubt hypotheses two and three.

H1 -- SPB do fly at temperatures below $58^O$F. In fact, according to the regression equation, we should expect to capture SPB on about 30% of all sample days with maximum temperatures of $58^O$F (using 5 or more traps).

H2 -- There is no sudden drop off in flight propensity with declining temperature. Rather, the excellent fit of the regression line shows that P drops off gradually to zero at about $42^O$F but see analysis of S below).

H3 -- Similarly, there is no sudden drop off in flight propensity with increasing temperature, but rather a steady decline in P at temperatures above $90^\circ$F or so to zero at about $105^\circ$F (but see analysis of S below). Evidence against this third hypothesis is not so strong as with the first two owing to a small sample of high temperatures. In particular, no temperatures were observed at or above the predicted temperature for zero flight activity.

While it would be possible to fit more complex curves to the percentage flight versus temperature data, we do not think that it would yield any new insights.

## CAPTURE FREQUENCY - SEPARATE DATA SETS

Table 3 gives the percentage flight activity broken down by data set. As the table clearly shows, the major differences are between time periods, not sites. During the beetle outbreak at the Bentley site, the frequency of capture at the Livingston site was comparable for all temperatures up to $80^\circ$F. At higher temperatures the frequency of capture declined at Camp Livingston while remaining steady at Bentley. For the post outbreak period capture frequency was substantially lower at both sites, rarely exceeding 30%.

Regressions fitted to each of these data sets (Model Ip) did not differ significantly for the lower temperature. For the upper temperature range the small sample sizes gave inconsistent results, with only the model for the B1 data significantly different from the rest. However, the B1 data had no observations above $94^\circ$F. Thus, only the pooled data gave any useful indication of flight activity at high temperatures.

SPB NUMBERS

As with frequency of capture, numbers of SPB increased with tempera-
ture to a peak, stayed roughly constant for a short temperature range, and
then dropped off.

Excellent results were obtained by fitting two linear regressions
(Model Is), one for 40-79°F and one for 80° + F (see figure 4).

$$S(T) = \begin{cases} 0 & T < 40 \\ -5.15 + .103T & (R^2 = .665; \ p < .0001) \quad 40 \le T < 80 \\ 16.2 - .167T & (R^2 = .608; \ p < .0001) \quad 80 \le T \end{cases}$$

Nonetheless, an examination of figure 4 shows that at low temperatures a
curve with increasing slope (e.g. exponential) would fit better than a
straight line. Thus, the data do suggest a substantial decline in SPB
activity around 54°F, below which numbers of SPB flying are very low.
This is in sharp contrast to the observation that the frequency with which
at least one SPB is caught drops off smoothly and steadily as temperatures
decline, going to zero at about 42°F. For higher temperatures, the basic
pattern is no different from the one obtained in the frequency analysis--a
steady decline in numbers of SPB with temperature. Of additional interest
is the shift in the peak of the graph. Frequency of capture was highest
at about 88°F, while number captured peaks around 79°F.

Since the pooled data combine two sites and two periods ("epidemic"
and "endemic"), separate analyses were performed on smaller data sets.

B1 - Epidemic

$$S(T) = \begin{cases} 0 & T < 40 \\ -14.1 + .282T & (R^2 = .763; \ p < .0001) \quad 40 \le T < 80 \\ 48.3 - .491T & (R^2 = .567; \ p < .005) \quad 80 \le T \end{cases}$$

Model Is for both pooled and B1 data overestimates the minimum flight temperature to be 50°F.

However, in the latter case there is much less suggestion in the graph of a sudden rise in flight activity at temperatures in the mid-fifties (see figure 7).

For both sampling areas, beetles were much more common through June 1980 than after. So another analysis was run combining the Bentley and Camp Livingston observations for the period September 1979 through June 1980 (B1 + L1). The resulting estimates for beetle numbers were:

$$
S(T) = \begin{cases} 0 & T < 40 \\ -7.63 + .153T & (R^2 = .725;\ p<.0001) \quad 40 \le T < 80 \\ 24.64 - .249T & (R^2 = .384;\ p<.01) \quad\quad 80 \le T \end{cases}
$$

Minimum and maximum flight temperatures were projected as 51°F and 98°F, respectively. Similar results were obtained using only the Camp Livingston observations from the high incidence period (L1).

$$
S(T) = \begin{cases} 0 & T < 40 \\ -1.56 + .0305T & (R^2 = .624;\ p<.0001) \quad 40 \le T < 80 \\ 4.52 - .0462T & (R^2 = .579;\ p<.001) \quad\quad 80 \le T \end{cases}
$$

Minimum and maximum flight temperatures were again estimated as 51°F and 98°F.

In all cases we find the same pattern: an incorrectly high estimate of minimum flight temperature and an incorrectly low estimate of maximum flight temperature. We also find a suggestion of an upward curve at lower temperatures and a downward curve at higher ones. Lacking any theoretical grounds for choosing a particular curve, we next fit exponential curves to

these data (Model II). This should give a better fit at the low and high temperatures. However, it will also give a sharp peak rather than plateau in the middle. This peak should _not_ be taken to be meaningful.

The exponential regressions were run on pooled data and outbreak data (B1), using log (SPB+.1) as the dependent variable.

Pooled:

$$S(T) = \begin{cases} 0 & T<40 \\ \exp(-7.41 + .123T) - .1 & (R^2 = .841;\ p<.001) \quad 40 \le T < 80 \\ \exp(12.97 - .145T) - .1 & (R^2 = .716;\ p<.0001) \quad 80 \le T \end{cases}$$

B1:

$$S(T) = \begin{cases} 0 & T<40 \\ \exp(-8.68 = .145T) - .1 & (R^2 = .865;\ p<.0001) \quad 40 \le T < 80 \\ \exp(10.53 - .103T) - .1 & (R^2 = .512;\ p<.005) \quad 80 \le T \end{cases}$$

These fits were generally better than the linear regressions, especially for the pooled data (see figures 5 and 8). Minimum and maximum flight temperatures projected from these regressions were: $42^{\circ}F$ and $105^{\circ}F$ for the pooled data; and $44^{\circ}F$ and $125^{\circ}F$ for the outbreak data. These are very reasonable projections for minimum flight temperature, and the pooled projection for maximum flight temperature looks reasonable. As noted earlier, the outbreak data set does not include enough high temperatures (maximum of $94^{\circ}F$) to be reliably used to project maximum flight temperature.

The final regression (Model III) did not require splitting the data into an increasing and a decreasing phase. Model III was fit to both pooled and epidemic data.

Pooled:

$$S(T) = \begin{cases} 0 & \text{for } T<40 \\ \exp(-21.7 + .595T - 00393T^2) - .1 & \text{for } 40 \le T \end{cases}$$

$$(R^2 = .723;\ p<.0001)$$

B1:
$$S(T) = \begin{cases} 0 & \text{for } T < 40 \\ \exp(-20.7 + .562T - .00348T^2) - .1 & \text{for } 40 \leq T \end{cases}$$

$$(R^2 = .834; \ p < .0001)$$

The fits were quite good, except for underestimating the peak levels of flight activity in the 70-85°F temperature range. Minimum temperature for flight was projected as 47°F for both equations. Maximum temperatures for flight were projected as 104°F by the pooled equation and 114°F by the B1 equation.

## DISCUSSION

Flight activity of southern pine beetles was measured two ways: percentage of sample days on which beetles were caught (P), and numbers of beetles caught (S). No data analysis was necessary to reject the hypothesis (H1) that 58°F is the minimum flight temperature for SPB. The data show they fly at temperatures down to 44°F. Fitting linear regression to P, we projected 42°F as the minimum flight temperature and 105°F as the maximum flight temperature. Linear, exponential, and normal curves were fitted to S. Only the latter two gave plausible estimates of minimum and maximum flight temperatures.

We cannot reach any strong conclusion regarding the two hypotheses (H2 and H3) which state that flight activity declines precipitously as the minimum and maximum temperatures are approached. Using P as the measure of flight activity leads to rejection of the hypotheses. But using S to measure flight activity supports the hypotheses. One speculative interpretation is that we are seeing two processes combined here: a pair of sharp temperature thresholds for each beetle, but a wide variation in these thresholds over

the population. A test of this idea would require an explicit mathematical model and substantial data on behavior of individual beetles, neither of which we have at this time.

Our main objective was to investigate flight at extreme temperatures. For us, measure P was most useful since it was less sensitive than S to variations in population density between samples. Where prediction of S is necessary, we caution that combining samples from areas with different beetle densities can substantially influence the results. While the shape of the S versus temperature curves are about the same, the absolute numbers vary considerably between samples (see figures 6 and 9). We also note that exponential and normal regressions of S versus temperature were much more successful than linear regressions. Perhaps some combination of exponential and normal models would be best.

| Data Set Name | Sample Site | Sample Period |
|---|---|---|
| Bentley | B | I————————————I<br>9/79              12/80 |
| B1 (outbreak) | B | I—————I<br>9/79      6/80 |
| B2 (postoutbreak) | B | I———I<br>7/80 12/80 |
| Camp Livingston (endemic) | L | I——————————————I<br>2/79                  12/80 |
| L1 | L | I—————I<br>9/79      6/80 |
| L2 | L | I———I<br>7/80 12/80 |
| Pooled | B+L | I=========I<br>I—————————I<br>2/79   9/79         12/80 |

Table 1: Data sets, sites and sample periods. Site B = Bentley and Site L = Camp Livingston. The doubled line for Pooled data sample period is a reminder that two complete sets of observations were recorded for that period, one at each site.

Table 2:  SPB flight activity at low temperatures.

| Max. Temp Degrees F | # Days Beetles caught | # Days Sampled | % Days Beetles caught | Grouped %'s |
|---|---|---|---|---|
| <40 | 0 | 7 | 0 | |
| 40 | 0 | 13 | 0 | |
| 41 | 0 | 1 | 0 | 0% |
| 42 | 0 | 4 | 0 | |
| 43 | 0 | 2 | 0 | |
| | | | | |
| 44 | 1 | 4 | 25 | |
| 45 | 0 | 0 | - | |
| 46 | 0 | 8 | 0 | |
| 47 | 2 | 6 | 33 | |
| 48 | 4 | 15 | 27 | 13% |
| 49 | 0 | 6 | 0 | |
| 50 | 1 | 17 | 6 | |
| 51 | 1 | 4 | 25 | |
| 52 | 1 | 12 | 8 | |
| 53 | 0 | 3 | 0 | |
| | | | | |
| 54 | 0 | 20 | 0 | |
| 55 | 1 | 3 | 33 | |
| 56 | 4 | 11 | 36 | |
| 57 | 0 | 4 | 0 | 22% |
| 58 | 8 | 23 | 35 | |
| 59 | 3 | 13 | 23 | |
| 60 | 5 | 20 | 25 | |

Camp Livingston and Bentley Data Sets combined.

Capture Days/Sample Days (%)

| Temperature Range (°F) | B1 | | B2 | | L1 | | L2 | |
|---|---|---|---|---|---|---|---|---|
| 32 – 40 | 0/9 | ( 0) | 0/1 | ( 0) | 0/9 | ( 0) | 0/2 | ( 0) |
| 41 – 45 | 1/9 | (11) | 0/0 | ( -) | 0/3 | ( 0) | 0/0 | ( -) |
| 46 – 50 | 4/21 | (19) | 0/4 | ( 0) | 3/20 | (15) | 0/6 | ( 0) |
| 51 – 55 | 2/16 | (12) | 0/5 | ( 0) | 1/13 | ( 8) | 0/7 | ( 0) |
| 56 – 60 | 12/21 | (57) | 0/10 | ( 0) | 5/19 | (26) | 0/9 | ( 0) |
| 61 – 65 | 14/21 | (67) | 0/3 | ( 0) | 9/25 | (36) | 0/5 | ( 0) |
| 66 – 70 | 38/42 | (90) | 1/7 | (14) | 20/39 | (51) | 4/11 | (36) |
| 71 – 75 | 33/33 | (100) | 1/13 | ( 8) | 26/28 | (93) | 8/13 | (62) |
| 76 – 80 | 37/37 | (100) | 3/18 | (17) | 41/50 | (92) | 3/18 | (17) |
| 81 – 85 | 41/41 | (100) | 3/13 | (23) | 28/34 | (82) | 2/10 | (20) |
| 86 – 90 | 41/41 | (100) | 1/33 | ( 3) | 32/49 | (65) | 1/19 | ( 5) |
| 91 – 95 | 13/13 | (100) | 11/45 | (24) | 8/14 | (57) | 8/48 | (17) |
| 96 – 101 | 0/0 | ( -) | 3/15 | (20) | 0/1 | ( 0) | 7/27 | (26) |

Table 3: Successful trapping days out of total sample days for each temperature range for four data sets: B1 = Bentley, September 1979 – June 1980; B2 = Bentley, July 1980 – December 1980; L1 = Camp Livingston, September 1979 – June 1980; L2 = Camp Livingston, July 1980 – December 1980. Percentages are given in parentheses.

FIGURE CAPTIONS

1. SPB Flight Activity:  Camp Livingston, LA.
   #SPB caught per trap each day Feb. 1979 - Dec. 1980.

2. SPB Flight Activity:  Bentley, LA.
   #SPB caught per trap each day Sep. 1979 - Dec. 1980.

   Note:  Vertical axes scaled differently for 1 and 2.

3. Southern Pine Beetle Activity
   % of trapping days on which SPB were caught vs. temperature ($^{O}$F) and linear regression lines for 40-88$^{O}$F and 89+$^{O}$F.
   Based on Bentley and Camp Livingston data sets combined.

   Note:  Numeric equations are given in text.

4. Southern Pine Beetle Activity
   SPB per trap per day vs. temperature ($^{O}$F) + linear regression lines for 40-79$^{O}$F and 80+$^{O}$F.  Based on Bentley and Camp Livingston data sets combined.

   Note:  Numeric equations are given in text.

   Note:  The y-axis is different from fig. 3.

5. SPB Activity as a Function of Maximum Temperature
   SPB per trap per day vs. temperature ($^{O}$F) + exponential regression lines (SPB = exp (a+bT)) for 40-79$^{O}$F and 80+$^{O}$F (see text for numeric values of parameters).  Based on Bentley and Camp Livingston data sets.

   Note:  This figure shows identical data to fig. 4, but nonlinear regressions.  The fit is much better and the projected minimum and maximum flight temperatures are more reasonable (see text).

6. SPB Activity as a Functional Maximum Temperature
   SPB per trap per day vs. temperature ($^{O}$F) + single nonlinear regression lines (SPB = exp (a+bT+cT$^{2}$)) (see text for numeric values of parameters).

   Note:  Same data as figures 4 and 5 but single nonlinear regression equation.

7. SPB Activity...
   Outbreak data (Bentley Sep. 1979 - June 1980).  SPB per trap per day vs. temperature ($^{O}$F) + linear regression lines.

   Note:  Corresponds to fig. 4, but uses a subset of the data (outbreak only).  The vertical scale is different from fig. 4.

8.  SPB Activity...
    Outbreak data (Bentley Sep. 1979 - June 1980).  SPB per trap per
    day vs. temperature ($^{\circ}$F) + exponential regression lines (SPB =
    exp (a+bT)).  Numeric values of parameters are given in text for
    equations for 40-79$^{\circ}$F and 80$^{\circ}$F.

    Note:  This graph corresponds to fig. 5, but uses a subset of the
           data (outbreak only).  Vertical scale different from
           fig. 5 (same as fig. 4).

           Low temp. regression is pretty good up to about 75$^{\circ}$F;
           regression is only so so above 75$^{\circ}$F.

9.  SPB Activity...
    Outbreak data (Bentley Sep. 1979 - June 1980).  SPB per trap per
    day vs. temperature ($^{\circ}$F) + single "normal-like" curve (SPB =
    exp (a+bT+cT$^2$)).  Numeric values of parameters are given in text.

    Note:  Same data as figures 7 and 8.  Corresponds to fig. 6 for
           pooled data.

SPB FLIGHT ACTIVITY CAMP LIVINGSTON, LA.
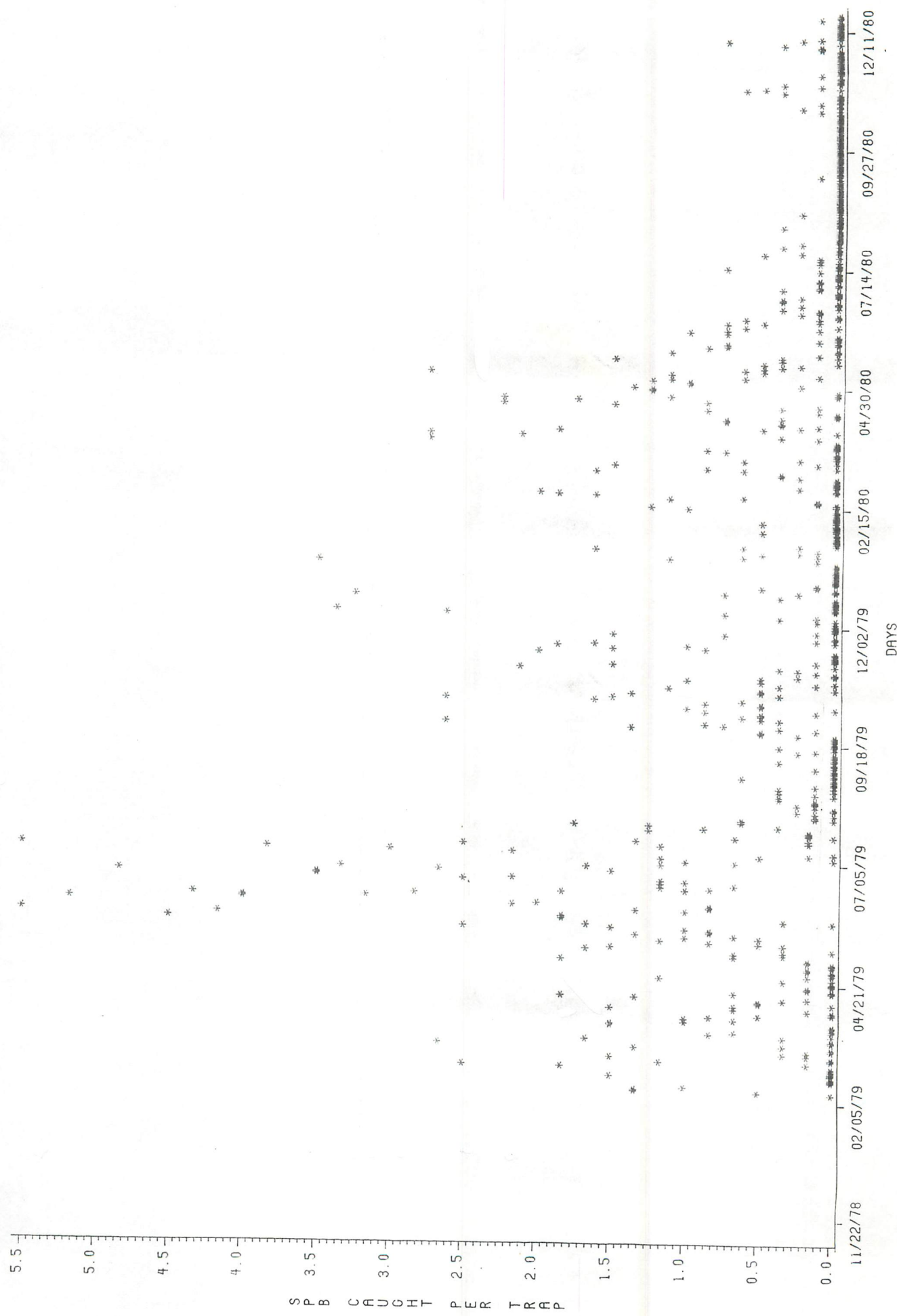
Figure 1.

SPB ACTIVITY:BENTLEY LA., 9/79–12/80
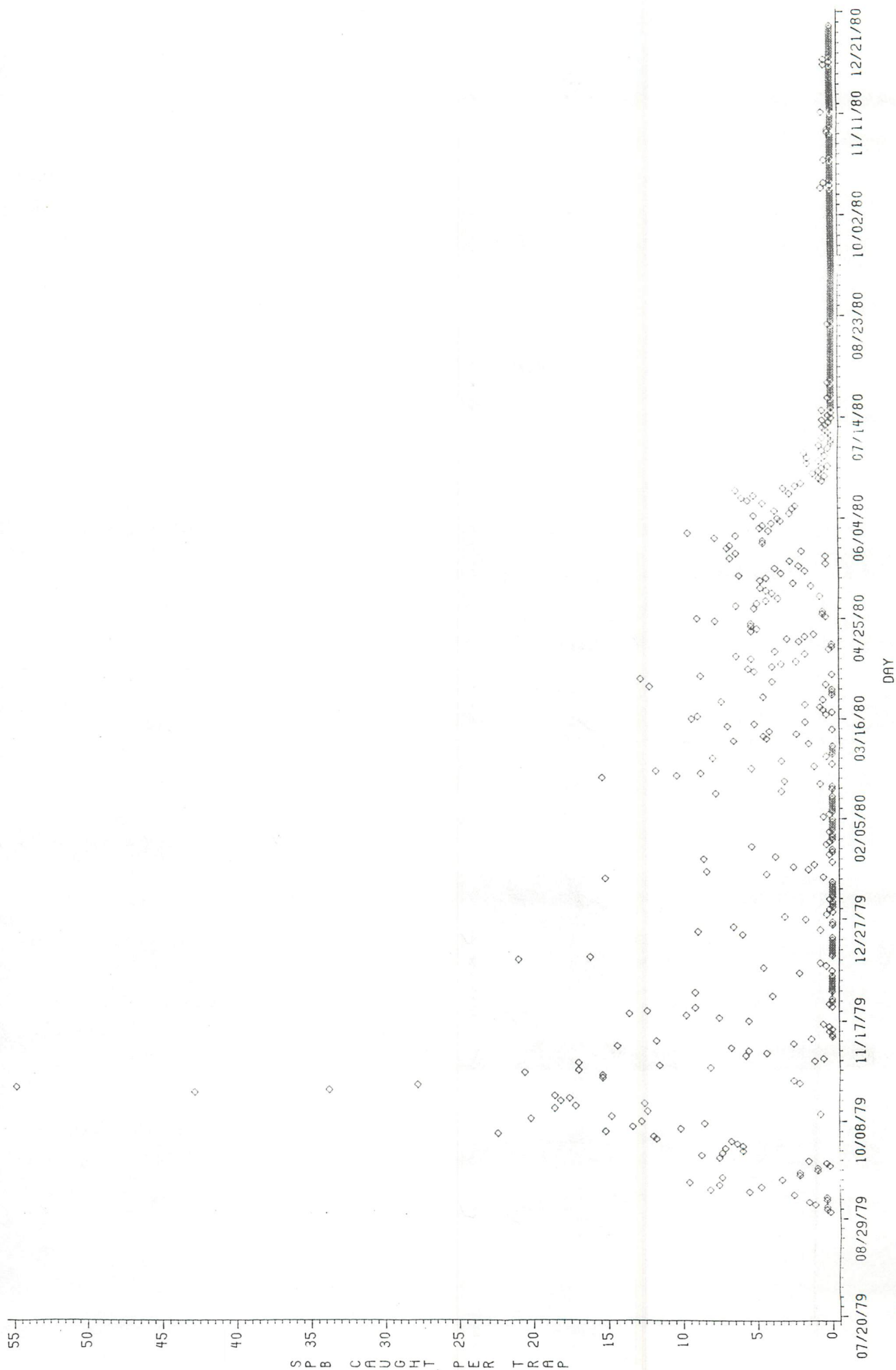
Figure 2.

# SOUTHERN PINE BEETLE ACTIVITY

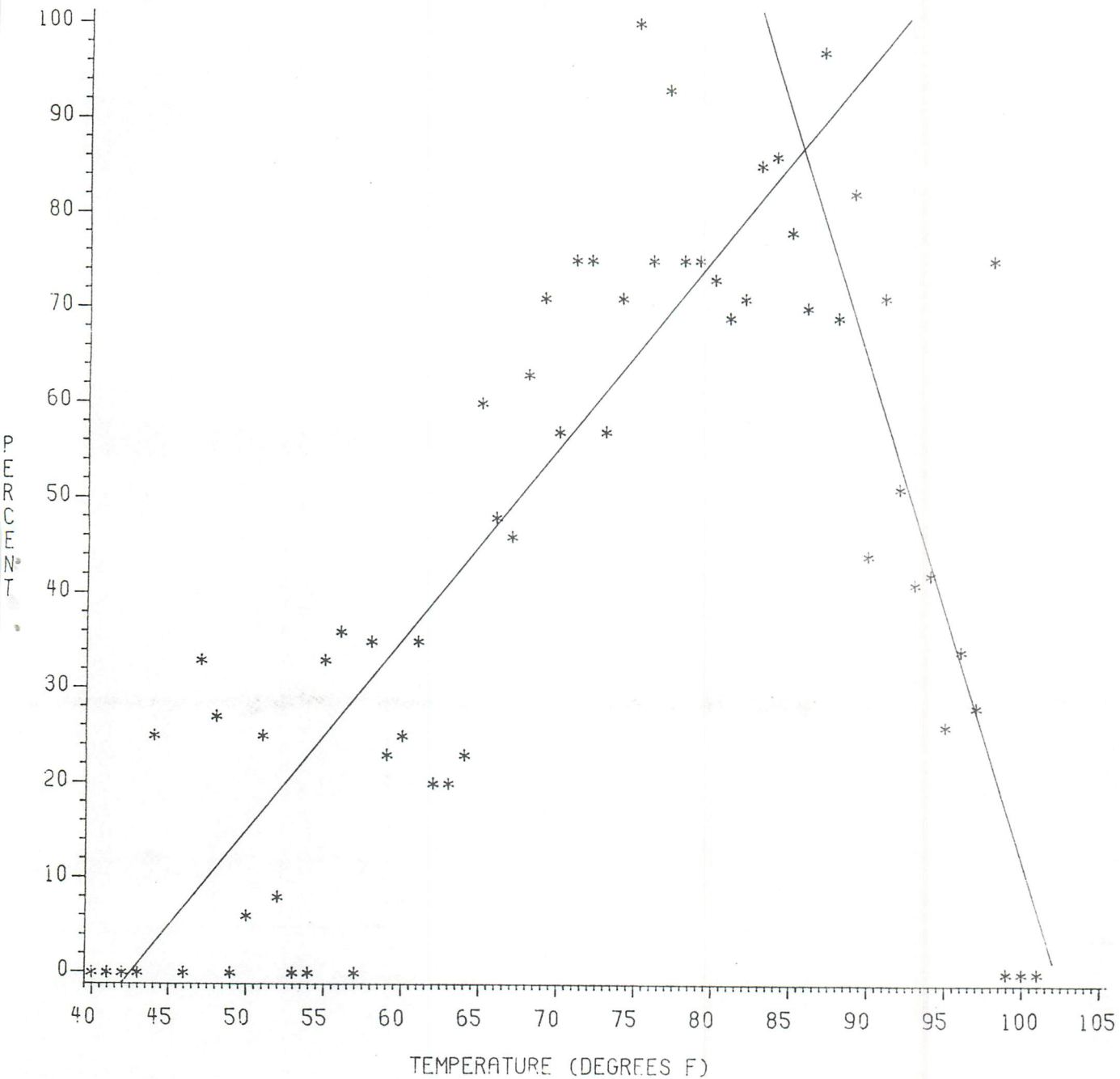## AS A FUNCTION OF MAXIMUM DAILY TEMPERATURE



Figure 3.

Note: THE PERCENT OF TRAPPING DAYS ON WHICH
SOUTHERN PINE BEETLES WERE CAUGHT,
AND REGRESSION EQUATIONS FITTED TO
40-88 AND 89-101 DEGREES F.

# SOUTHERN PINE BEETLE ACTIVITY

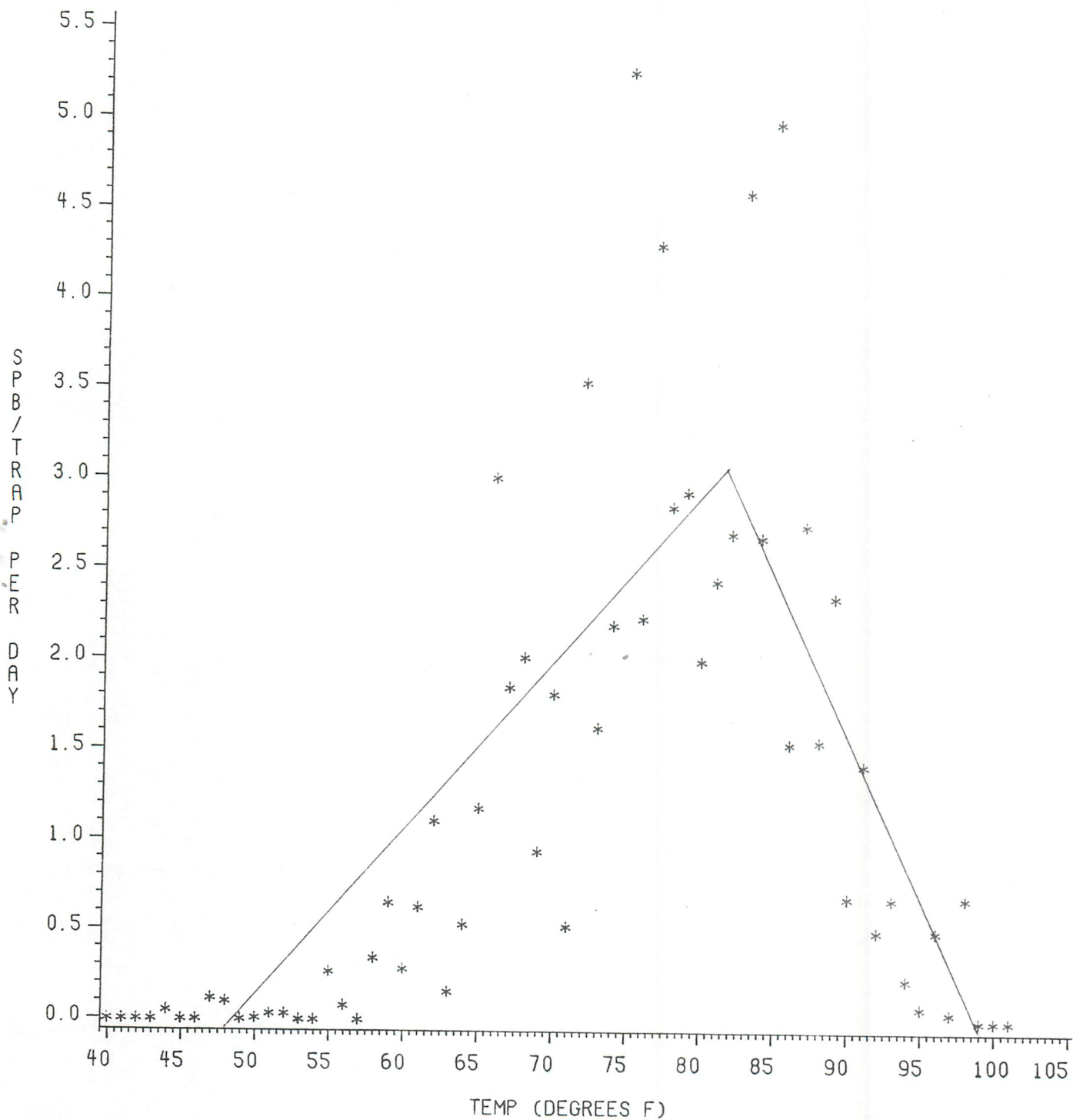### AS A FUNCTION OF MAXIMUM DAILY TEMPERATURE
### POOLED DATA:FEB 1979 TO DEC 1980



Figure 4.

Note:  THE NUMBER OF SOUTHERN PINE BEETLES PER
TRAP THAT WERE CAUGHT ON EACH DAY
AND REGRESSION EQUATIONS FITTED TO
40-79 AND 80-101 DEGREES F.

# SPB ACTIVITY AS A FUNCTION
# OF MAXIMUM DAILY TEMPERATURE

POOLED DATA:FEB.,1979-DEC.,1980
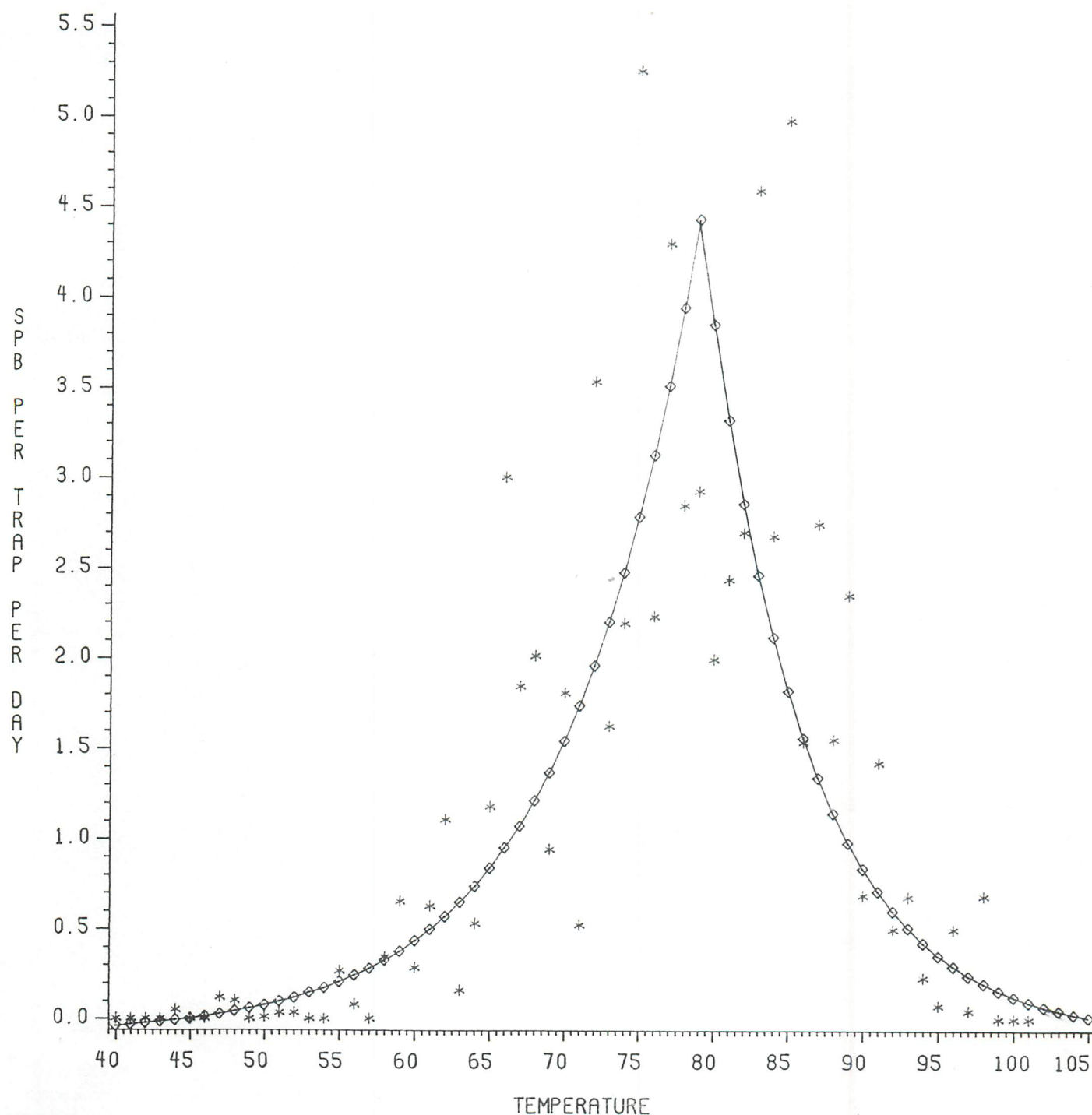


Figure 5.

Note:  THE NUMBER OF SOUTHERN PINE BEETLES PER
TRAP ARE STARRED.  THE SQUARE POINTS
ARE VALUES REPRESENTING EXP(PREDICTED -0.1).

# SPB ACTIVITY AS A FUNCTION
# OF MAXIMUM DAILY TEMPERATURE
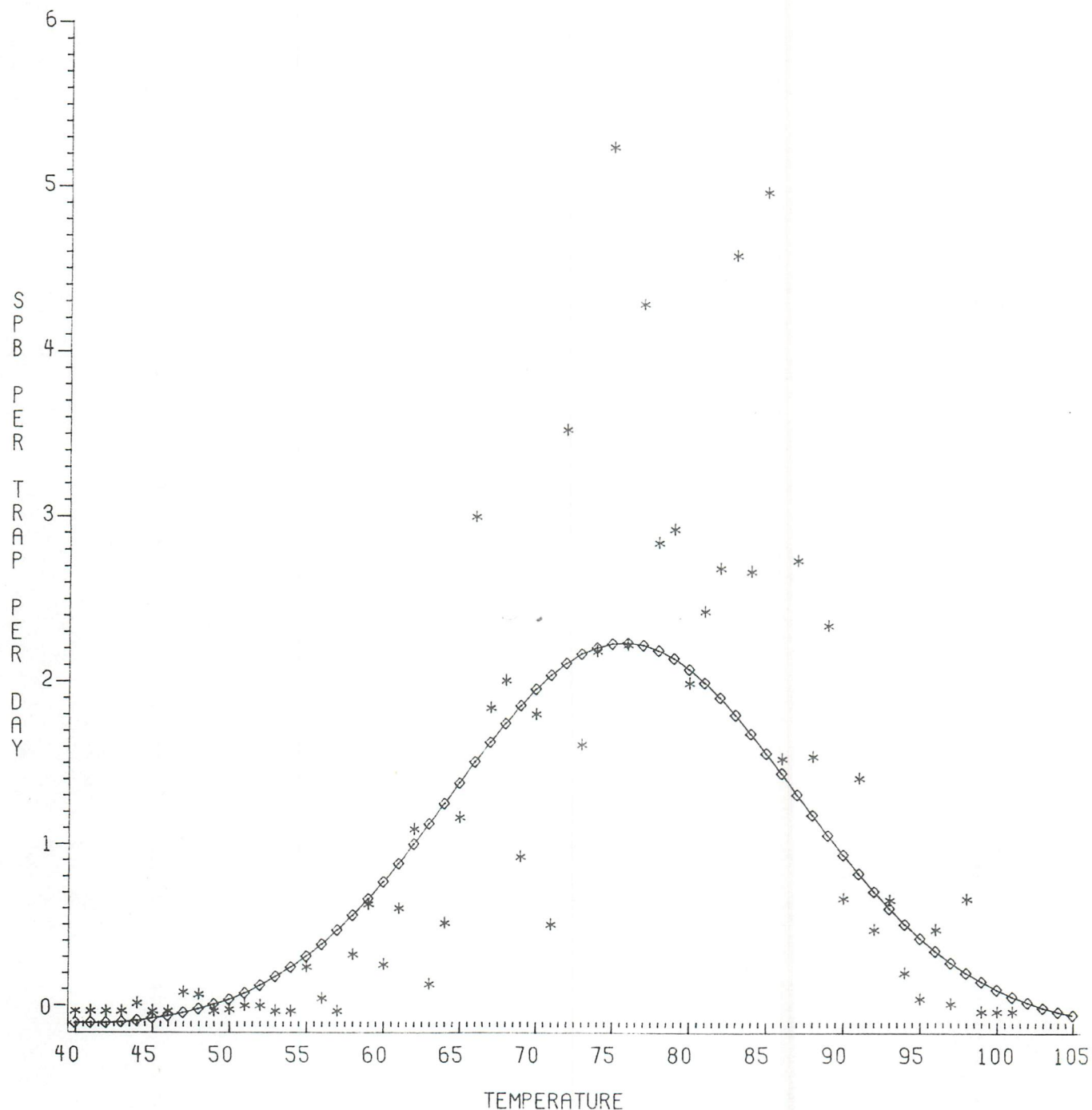
Figure 6.

Note: THE NUMBER OF SOUTHERN PINE BEETLES PER
TRAP ARE STARRED.  THE SQUARE POINTS
ARE VALUES REPRESENTING EXP(PREDICTED).
THE INDEPENDENT VARIABLES IN THE REGRESSION
EQUATION ARE MAXIMUM TEMPERATURE AND MAXIMUM
DAILY TEMPERATURE SQUARED

# SOUTHERN PINE BEETLE ACTIVITY

### AS A FUNCTION OF MAXIMUM DAILY TEMPERATURE
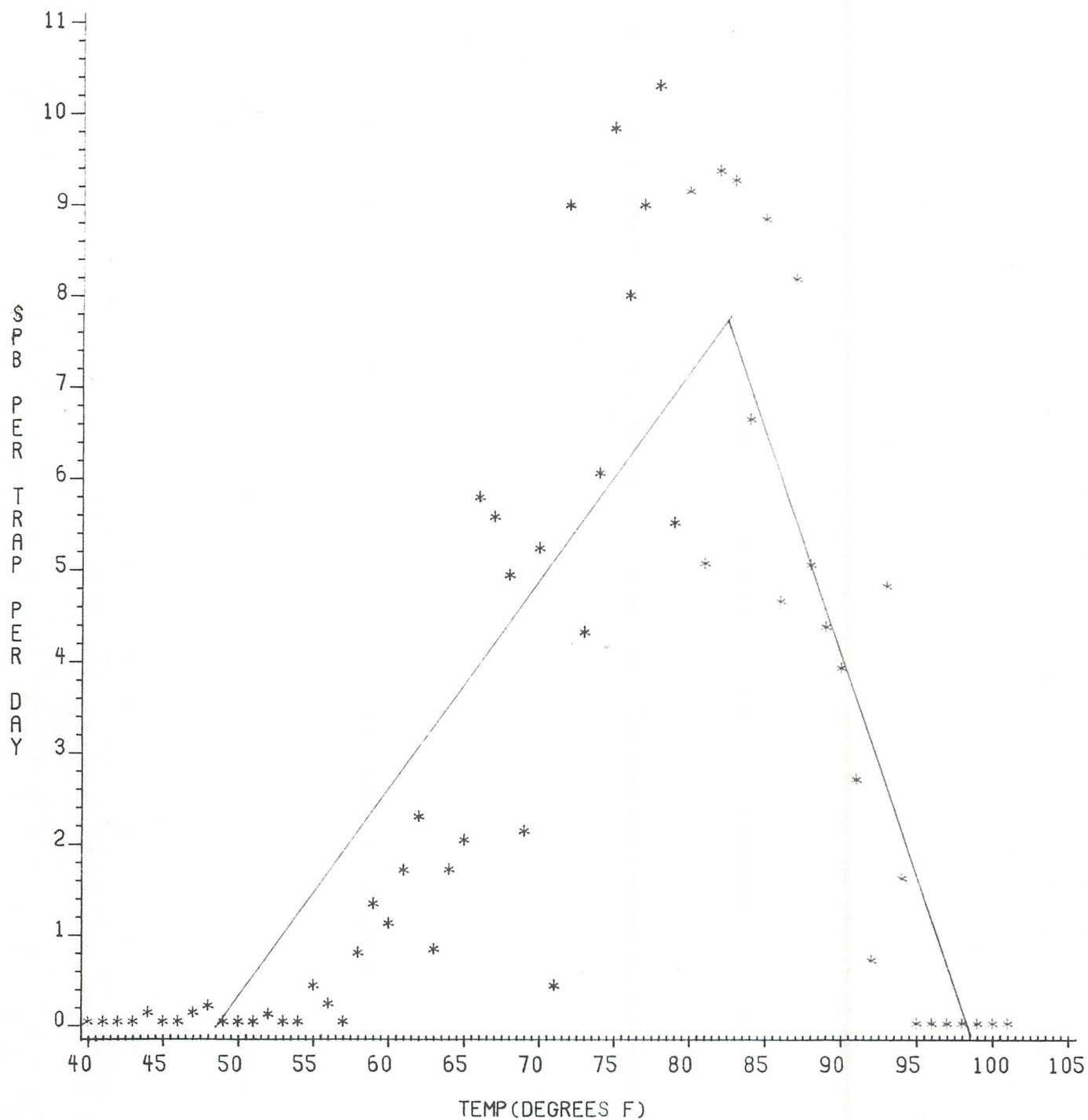### BENTLEY, LA. SEPT 1979-JUNE 1980



Figure 7.

Note: THE NUMBER OF SOUTHERN PINE BEETLES PER
TRAP THAT WERE CAUGHT ON EACH DAY
AND REGRESSION EQUATIONS FITTED TO
40-79 AND 80-101 DEGREES F.

# SPB ACTIVITY AS A FUNCTION
# OF MAXIMUM DAILY TEMPERATURE

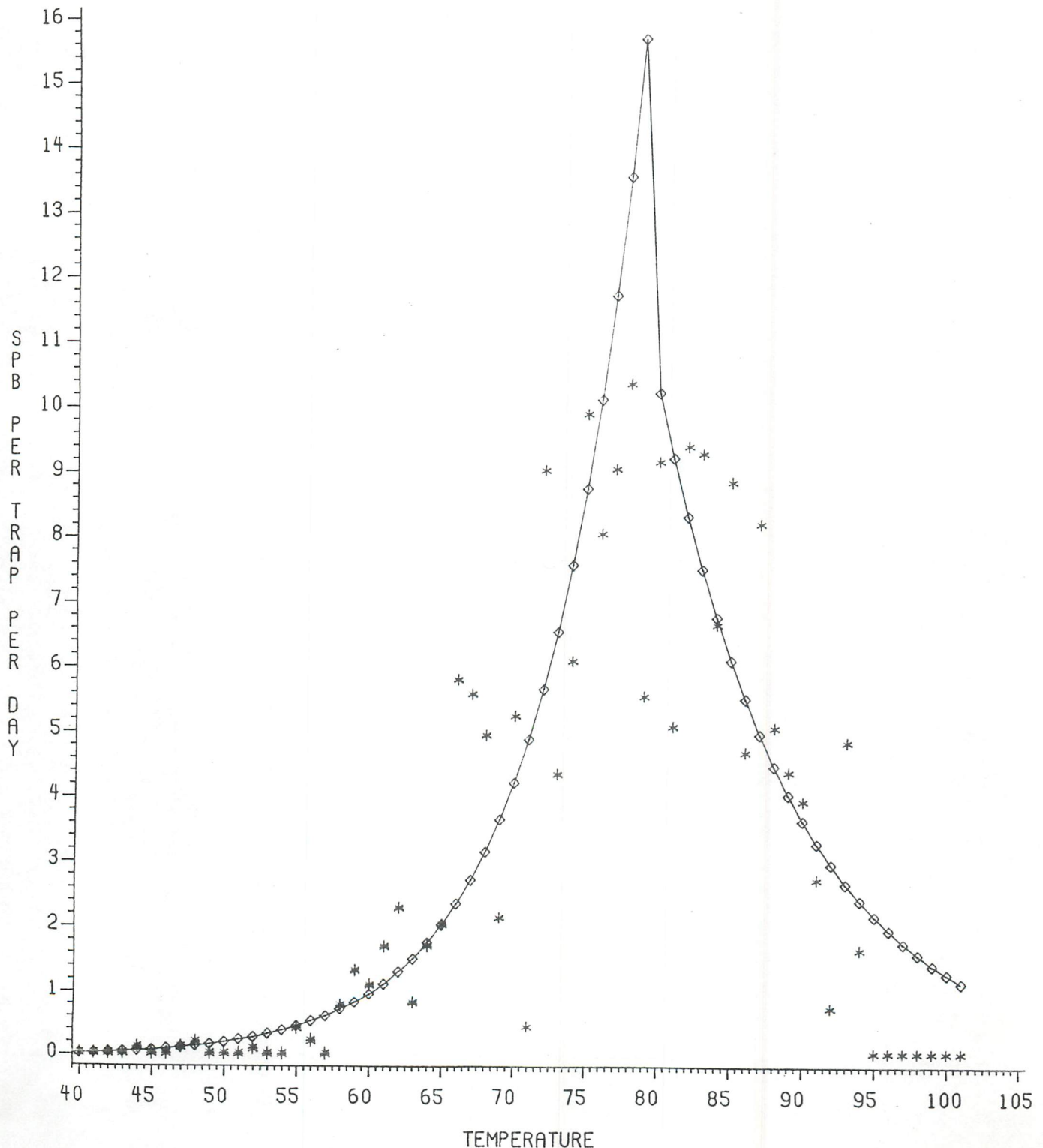BENTLEY, LA. : SEPT., 1979–JUNE, 1980



Figure 8.    Note: THE NUMBER OF SOUTHERN PINE BEETLES PER
TRAP ARE STARRED.   THE SQUARE POINTS
ARE VALUES REPRESENTING EXP(PREDICTED).

# SPB ACTIVITY AS A FUNCTION
# OF MAXIMUM DAILY TEMPERATURE

BENTLEY, LA. : SEPT. , 1979-JUNE, 1980
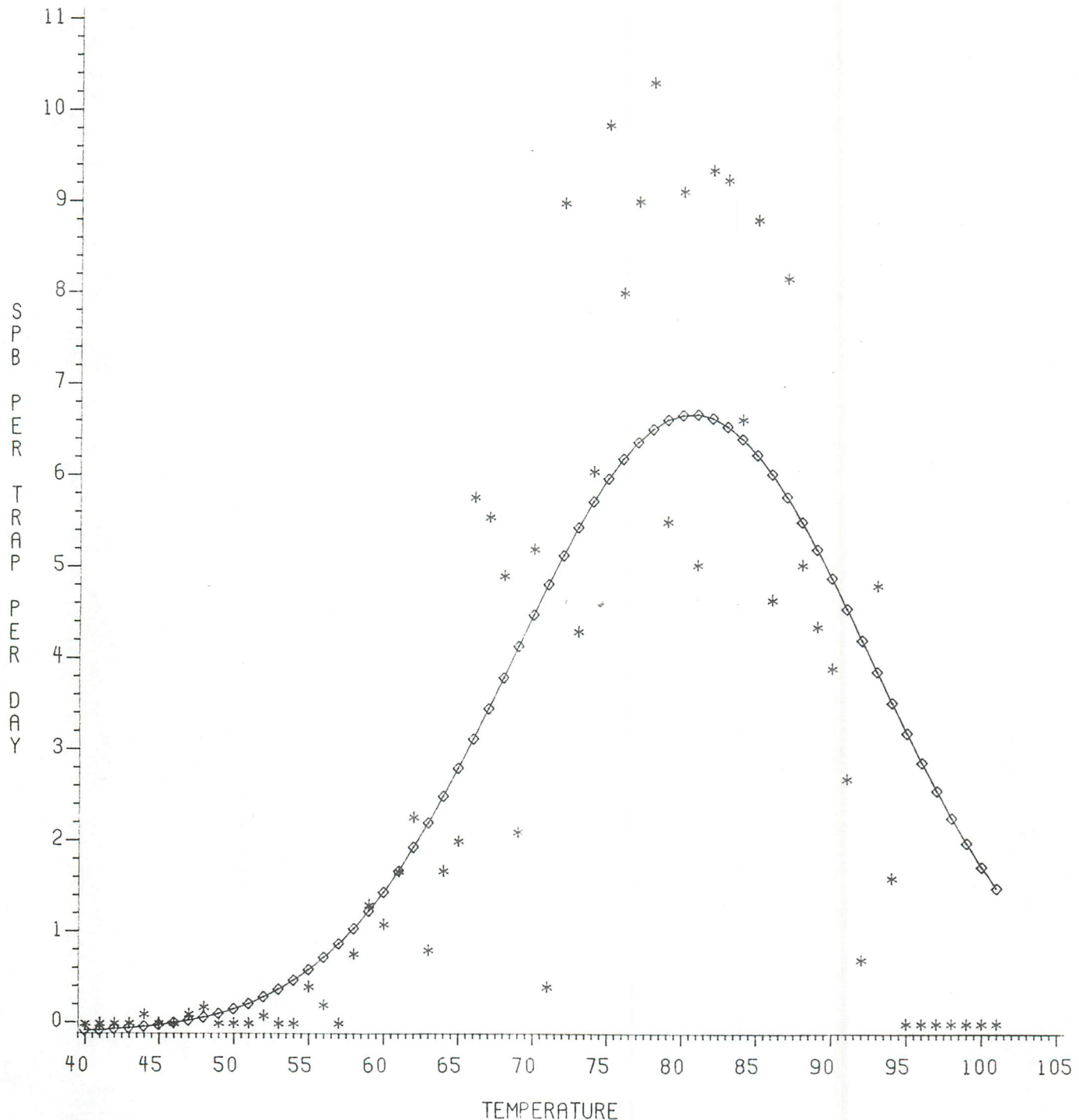


TEMPERATURE

Figure 9.    Note:    THE NUMBER OF SOUTHERN PINE BEETLES PER
TRAP ARE STARRED.   THE SQUARE POINTS
ARE VALUES REPRESENTING EXP(PREDICTED).
THE INDEPENDENT VARIABLES USED IN THE REGRESSION
EQUATION ARE MAXIMUM DAILY TEMPERATURE
AND MAXIMUM DAILY TEMPERATURE SQUARED.